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THE UNIVERSITY OF ALBERTA

COMPARISON OF THREE TECHNIQUES FOR ASSESSING THE ERODIBILITY OF CULTIVATED SOILS.

BY

THOMAS W. GODDARD

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN
PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

IN

SOIL CONSERVATION

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA
FALL, 1988

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled COMPARISON OF THREE TECHNIQUES FOR ASSESSING THE ERODIBILITY OF CULTIVATED SOILS submitted by THOMAS WILLIAM GODDARD in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in SOIL CONSERVATION.

D S Chanasyk
(Supervisor)

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Date: September 19, 1988

Abstract

The ability to differentiate cultivated soils on the basis of aggregate stability would be useful in predicting resistance of farmed soils to water erosion. The waterdrop impact method of assessing aggregate stability was used in an examination of 63 cultivated soils from Alberta. The samples were also subjected to wet sieving and the K factor of the Universal Soil Loss Equation was calculated using a nomograph equation with both a restricted and unrestricted organic matter value. The K factor calculated both ways were the best variables to separate the samples on the basis of erosion class, soil series and, textural class. The K factors separated erosion classes the most and textural classes the least. Waterdrop and wet sieving variables separated less than half the data into groups. The waterdrop method was best correlated (r=0.63) with the wet sieving variable representing the % aggregates >2 mm, while the K factor was best correlated (r=-0.38) with the wet sieving variable representing the % aggregates between 0.5 and 2 mm. Waterdrop indices were not correlated with K factors. Regression analysis allowed predictive equations to be derived for the K factors explaining 87 to 99% of the variability in K. Predictive equations derived for waterdrop and wet sieving variables could predict no greater than 60% and 45% respectively, of the dependent variables. Eighty-one percent of the soils examined contained parameter values beyond that allowed by the nomograph derivation of the K factor. To assess effectively soil erodibility for Albertan soils, a multi-faceted approach is required within which the waterdrop and the wet sieving of the coarse to medium aggregate fraction may play a part along with field rainfall simulation. Use of the USLE on the Canadian prairies without modifications and/or verification of the method used to determine the K factor would constitute a misuse of the equation. An efficient and accurate method of ranking erodibility of western Canadian soils is needed for farm conservation planning.

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1.0 INTRODUCTION

Water erosion in Canada has been a persistent problem since farmland was first cultivated but has become an increasing concern in the past decade. It has been reported to be a significant degradation process even in the more arid areas of the prairies where wind erosion was thought to be the main erosion process (Pettapiece et al., 1983).

Erosion, being a selective process, removes the finer, desirable portion of the soil (clay and organic fractions) and leaves the poorer. In so doing, the productivity of the soil is reduced, poorer crops are produced and the soil is left further exposed to the erosive factors of climate resulting in increased erosion. Consequent deterioration of soil quality and loss of productivity is a growing concern. In response to this concern scientists have produced maps of soil erosion risk. On the prairies the maps have only been developed at a broad provincial scale. In the production of these maps it was necessary to estimate the potential erosion risk of the different soils. Often the Universal Soil Loss Equation (USLE) developed in the U.S.A. was used (Van Vliet et al., 1976; Tajek et al., 1985; Vold et al., 1985). The USLE is also used on a site basis (Van Vliet and Wall, 1979; de Jong et al., 1986). The only attempts made to verify the factors used in the USLE for Canada have been for the climatic erosivity factor (Wall et al., 1983; Kachanoski and de Jong, 1985). Thus the continued use in Canada constitutes a misuse of the equation (Wischmeier, 1976) until the factors are verified for Canada or an equivalent estimate of predicting potential risk of water erosion is developed. It would be desirable to produce erosion potential maps with a known accuracy and be able to assess quickly and inexpensively water erosion risk at a field scale in order to provide conservation advice at the farm level.

In addition to a climatic erosivity factor, the other important factor in the USLE is the soil erodibility value, the K factor, a composite factor of several soil properties which if not obtainable by long term plot studies can be approximated by a rather complex nomograph. In order to use the nomograph the soil must be subjected to a variety of tests.

Considering this and the inherent shortcomings of the nomograph determination of K, an alternative, quick method of determining relative erodibility would be desirable. The initial step in the process of soil erosion by water is the breakdown of the soil aggregates into smaller sub-aggregates and primary particles. Thus, a measure of aggregate stability can be related to the resistance to water erosion of a given soil. The waterdrop technique as presented by McCalla (1944) provides a method of measuring aggregate stability and may provide an alternative method of approximating the K value of the USLE.

The objectives of this study were a) to examine the waterdrop method of assessing aggregate stability as a quick, inexpensive, and accurate method to rank cultivated soils on the basis of their resistance to raindrop forces; b) to assess the suitability of the method to approximate the soil erodibility factor, K, of the Universal Soil Loss Equation; c) to assess the wet sieving method of aggregate stability for separation of soils on the basis of erodibility; and d) to examine interrelations between the waterdrop method, the K factor and, wet sieving.

2.0 LITERATURE REVIEW

Water erosion of soil is considered to be a function of the erosive capacity of climate and the soil erodibility (Hudson, 1981). The erosive nature of climate is considered to be rainfall energy although recent research has found snowmelt to be a significantly erosive force (Wischmeier, 1959; Wischmeier and Smith, 1978; McCool et al., 1982; Chanasyk and Woytowich, 1987). Soil erodibility can be further divided into a function of soil physical properties and soil management (Hudson, 1981). If management and topography (cultivation, crop, slopes, etc.) are held constant together with the climatic conditions, then soil physical properties will affect water erosion losses. The term "soil physical properties" can include the obvious such as texture but also structure and tilth which are more a combination of physical, biological and chemical properties. Soil structure can be defined

as "the manner in which soil particles are assembled in aggregate form" (Hausenbuiller, 1972). The initial step in water erosion has been recognized as the breakdown of these soil aggregates by water (as impacting rain or surface runoff) to small aggregates and primary particles which seal the soil surface resulting in reduced infiltration so that water builds up at the surface and runoff occurs (Ellison and Slater, 1945; Ekern, 1950; Bisal, 1966; Young and Onstad, 1982). Therefore, the erodibility of a soil to water erosion will depend on the resistance of aggregates to the forces of raindrops and overland flow. The stability of soil aggregates has been found to correlate well with several factors and constituents to be discussed here.

2.1 Factors influencing aggregate stability

Soil aggregate stability has been found to increase with increasing clay content (Middleton, 1930; Kemper and Koch, 1966; Bergsma and Valenzuela, 1981; Wustamidin and Douglas, 1985). Kemper and Koch (1966) found the relationship between aggregate stability and clay to be hyperbolic (increasing with diminishing returns) without any sharp breaks. Chepil (1955) made artificial soils with inverse proportions of sand and clay only and found that the percentage of aggregates > 0.84 mm increased with an increasing proportion of clay. This relationship was linear when the clay proportion was greater than 20%. The aggregate stability versus clay graph of Kemper and Koch (1966) had a similar slope. Waterdrop energy required for aggregate disruption was found to be directly proportional to clay content and inversely proportional to sand content (Bruce-Okine and Lal, 1975). Type of clay is also correlated with aggregation and aggregate stability. Smectite clays form aggregates more readily but slake more easily than kaolinites particularly when prewetted under vacuum (Mazurak, 1950; Robinson and Page, 1950; Morgan, 1986). Wustamidin and Douglas (1985) found no significant correlation between clay and artificial raindrop energy. However, 16 of the 17 soils they tested were dominantly illitic or kaolinitic clays.

Organic matter is positively correlated with aggregation and the effects of organic materials on aggregation have been extensively reviewed (e.g.: Harris et al., 1966; Lynch and Bragg, 1985; Burns and Davies, 1986).

It is not the mere addition of organic matter but the decomposition of it that leads to aggregation (Harris et al., 1966; Burns and Davies, 1986). Since decomposition occurs continuously (provided conditions are favourable), the kind of organic matter additions, amount of additions and factors influencing microorganisms, such as tillage, become important. Much work has been done on the effects of crop rotations and crop type on soil aggregation (Harris et al., 1966; Lynch and Bragg, 1985; Burns and Davies, 1986). The greatest amount and stability of aggregates occur under continuous perennial forage (usually grass) with aggregation and aggregate stability decreasing with decreasing frequency of forage in a rotation and/or the increasing frequency of fallow and cultivation (Harris et al., 1966; Dormaar and Pittman, 1980; Lynch and Bragg, 1985; Baldock and Kay, 1987).

Organisms are involved in two ways in mediating aggregation. They can either mechanically bind particles of soil together or produce binding agents through synthesis or the decomposition of organic materials (Lynch and Bragg, 1985). Early studies placed fungi and actinomycetes at the top of the list of organisms promoting aggregation (Harris et al., 1966). Some of these studies noted, however, that the initial fungal growth was destroyed by colonizing bacteria and a reduction of stability occurred. Ephemeral contributions of filamentous organisms to aggregation have been confirmed in more recent studies (Burns and Davies, 1986). Nevertheless, fungi are important in that, like roots, there is a flourish of growth that physically binds soil particles and eventually acts as substrate (both physical and metabolic) for subsequent microbial populations. Harris et al. (1966) noted that it is difficult to establish whether aggregation by fungi is due to "physical enmeshing" or the adhesion of soil particles to the excreted mucilage coating the hyphae.

Lynch and Bragg (1985) noted that dead fungi could continue to bind soil particles physically if protected within an aggregate. Bacteria are responsible for aggregation in direct and indirect ways. There has been some evidence that bacterial appendages, like those of fungi, may be responsible for some mechanical adhesion of particles, although other studies have shown a peak in aggregation lagging a peak in bacterial populations indicating a role of binding agents produced by bacteria (Harris et al., 1966).

Aggregate stability is positively correlated with polysaccharide content and studies have shown that when polysaccharides were removed with periodate, larger aggregates (>50 mm) were unaffected indicating polysaccharides play a more important role in formation of small aggregates (Burns and Davies, 1986). Baldock et al. (1987) in Ontario supported this, observing that while total carbohydrate content was not significantly influenced by cropping treatment, it increased as aggregate size decreased. Burns and Davies (1986) suggested that mycelial structures and mucilages are involved in different stages of aggregate stabilization with filamentous organisms being involved primarily in aggregate formation (and thus found in larger pores) while polysaccharides may be more important in the processes of cementing clay particles to form microaggregates.

The end product of organic decomposition is a dark-coloured, heterogenous, colloidal mixture called humus often separated by chemists into two further terms such as insoluble humin and soluble humic colloids (Lynch and Bragg, 1985). Humic colloids are often separated into fulvic and humic acids and include polysaccharides, proteins and other complex substances containing aromatic rings. Burns and Davies (1986) reported that polysaccharides involved in aggregation are predominantly microbial in origin because of the extraction of galactose, glucose and mannose from aggregates which are constituents of microbial polymers. Smaller quantities of the plant saccharides arabinose and xylose found have led to the use of a ratio of galactose and mannose to arabinose and xylose (G+M:A+X) in the analysis of soil polysaccharides (Burns and Davies, 1986). Baldock et

al. (1987) found there was a significant amount of galactose from both corn and bromegrass in their study so they modified the ratio to M:A+X and found that the dominantly corn rotations had a significantly larger ratio than bromegrass, showing the greater contribution of microbial polysaccharides in annual cropping systems. Baldock et al. (1987) further reported that there was no correlation between either total or individual sugars and aggregate stability over the different cropping systems and suggested further study may be fruitful in more specific extraction procedures, measurements of roots and fungal hyphae and amounts of plant and microbial mucilages. The variation and complexity of results of experiments on the effects of plant and microbial products on aggregation point to a continuous dynamic process of aggregation caused by the degradation and transformation of organic materials. At any one point in this continuum there are several mechanisms of aggregation playing a role.

The mechanisms involved and factors affecting the adsorption of organic molecules (and microbial cells) and soil particles have been reviewed elsewhere (Harris et al., 1966; Theng, 1982; Lynch and Bragg, 1985) and can briefly be listed as follows:

1. Cation bridging between negatively charged groups (e.g. carboxyl) on the organic polymer and adsorbed cations on clay surfaces.
2. Cation bonding between protonated organic group and negative clay surface.
3. Hydrogen bonding between the O atoms of the clay and the negatively charged organic polymer or, between two polymers.
4. Van der Waals forces between non-ionic groups.

These mechanisms are modified or favoured under the influence of many factors including: molecule flexibility; length and structure (molecular weight); number and kind of active groups; degree of substitution; type of clays; moisture content; cations in solution; and pH.

Cultivation is another factor affecting soil aggregation but it also influences the soil climate (moisture, temperature, aeration, etc.) which influences aggregation. Thus, it is often hard in aggregation research to isolate the effect due only to cultivation. Harris et al. (1966) reported that extensive cultivation is detrimental and the damage (reduction of aggregation) is a function of moisture content, increasing when soil is worked above or below some optimum moisture content. Biederbeck et al. (1981) reported that the degree of surface cloddiness is a function of soil texture, moisture content, kind of implement and speed. They observed that aggregation was lower after a fallow year and in the years following the breaking of sod. Some of this reduction in aggregation was thought to be due to cultivation (Biederbeck et al., 1981). Anderson and Wenhardt (1966) examined various cultivation treatments of summerfallow over an eight year period and evaluated the effect on the basis of aggregation (% soil <0.84mm = "erodible soil"). The authors found that a plow + heavy duty cultivator treatment gave greater aggregation in the fall measurements but when subsequent spring measurements were made, the blade cultivator treatment yielded the greatest aggregation. These differences were only significant in approximately 50% of the study years. They noticed that the blade cultivator left more crop residue on the surface, thus, there could be a further effect of microbial activity, moisture and freeze/thaw action to yield more springtime aggregation. Biederbeck et al. (1981) found that the year to year variability of cultivation results may be due to the influence of more dominant factors affecting aggregation.

The effect of freezing and thawing on aggregation was singled out in the 1930s for detailed study and early conclusions were that aggregation was not affected or that it was inversely related to the rate of freezing and dependent on the manner in which the soil moisture crystallized (Harris et al., 1966). Harris et al. (1966) also reported that later studies concluded the destructive effects of freeze/thawing were worst at high moisture contents, which contradicted earlier studies. Several researchers found that alternate

freezing and thawing broke down larger clods and aggregates but did not affect the smaller aggregates <0.25 mm (Harris et al., 1966). Alderfer (1950) observed in Pennsylvania field studies that two months of continuous freezing at moisture contents near field capacity produce the most stable aggregation but that the effects of freezing over winter were temporary and subject to alteration in the "very early spring". It was further noticed by Alderfer (1950) that the "continuous freezing" winter had constant snow cover and therefore relatively constant soil moisture whereas winters with many freeze/thaw cycles that produced fewer water stable aggregates also had little or no snow covering the fields. Bisal and Nielsen (1964) conducted laboratory studies with freeze-drying equipment and noted the difficulty of separating the effects of freezing from the effect of wetting as thawing occurred. They found that freezing moist soil resulted in a breakdown in aggregate size but if the soil was allowed to thaw in a moist state the soil consolidated. The ultimate aggregation depended on the soil texture and moisture content at time of drying. If the moisture was removed while frozen and the soil allowed to thaw, the aggregation was much less and the soil more erodible (wind). The importance of moisture content in the freeze/thaw effect was observed by Anderson and Wenhardts' (1966) field studies. They found that the winters where aggregation decreased from fall to spring were also the winters with little precipitation. The winters where no differences in aggregation occurred were found to have more normal precipitation.

In attempts to isolate the effect of wetting and drying on aggregation, researchers found that aggregation is a function of soil type, aggregate moisture at time of wetting, and intensity of wetting (Harris et al., 1966). Aggregate stability in water is the result of two groups of opposing forces in the aggregate yielding to the driving force of water entry into an aggregate (Harris et al., 1966; Baver et al., 1972; Emerson, 1977). The driving force for water entry is the affinity or lack thereof, of the internal surfaces for water (hydrophilic, hydrophobic) and pore size (capillarity). The opposing forces within the aggregate are the

cohesive forces (intra-aggregate bonds) versus the pressure forces of entrapped air and swelling (due to hydration) of aggregate constituents. Water entering a completely dry aggregate is drawn into small pores with a great force. If air ahead of the wetting front has no exit, the pressure builds and the aggregate fails along its weakest point. In addition, the swelling stress due to hydration will be substantial if there is a large proportion of smectite clays in the aggregate and/or oriented clays coating the pores. Researchers (e.g. Mazurak, 1950; Robinson and Page, 1950; Emerson, 1977) found support of this explanation in that dry aggregates of bentonite, kaolinite and illite slaked upon wetting at atmospheric pressure. When wet under a vacuum, kaolinite did not disaggregate or broke into a few large pieces (entrapped air is dominant factor) while bentonite slowly disaggregated (swelling is still dominant factor). Cernuda et al. (1954), examining slaking of aggregates moistened under vacuum to tensions of pF 0 to 7, found "explosive" slaking of very dry aggregates while the moist aggregates were the most resistant. Other researchers measuring aggregate stability of soils at different field moistures have found decreasing stability with decreasing moisture contents (Gish and Browning, 1948; Alderfer, 1950; Bourget and Tabi, 1966).

Soil aggregation and aggregate stability have been correlated with the time of year or season. The general view is that the number of water stable aggregates increase from the spring to a maximum in the fall and a minimum in the winter (Chepil, 1954; Anderson and Wenhardt, 1966; Harris et al., 1966; Imeson and Vis, 1984a). The breakdown over winter is primarily due to frost action as a function of moisture content, as mentioned earlier, and the spring increase in aggregation is associated with ideal conditions for microbial activity (moisture, available supply of organic matter). Combeau (1965) found that the relative change in aggregation throughout the year was the same in central Africa as it was near Paris. The maximum occurred in the summer in France and in the dry season in Africa.

The curves followed the seasonal moisture curves and the aggregation of the temperate soils were further modified by temperature (positively).

Inorganic compounds play a part in soil aggregation. Positive relationships have been determined between aggregation (and aggregate stability) and sesquioxides (Al and Fe), divalent substitution for monovalent ions, calcium carbonate, and silicate (Kemper and Koch, 1966; Baver, 1972; Emerson, 1977; Hoyt, 1981). Often in surface horizons, the effect of these compounds on aggregation is modified or masked by the organic fraction (Emerson, 1977).

2.2 Assessing aggregate stability

Numerous methods of assessing soil aggregate stability have evolved over the years, all of them imparting some force or collection of forces on aggregates, resulting in the relative ranking of different soils based on their resistance to the forces imposed.

Low (1954) compared several methods for assessing soil structure, noting that it is very difficult to measure structure directly and thus more often a soil property is measured which is a function of structure. Some of the properties that infer something about soil structure are infiltration, drainage, percolation, aeration rates, pore space, degree of compaction, bulk density, 'available' water, and ease of cultivation (Russell, 1949; Low, 1954). These measurements do not measure stability when done only once but if repeated before and after a treatment, they will assess the soil's resistance (stability) to that treatment. Measurements of structural stability require forces to be applied and usually entail soil moving with respect to a stationary container (sieving) or the application of a force on the soil (wet sieving, waterdrops, penetrometer, ultrasonification).

The extent to which soil disperses in water has been used as an erodibility index for a long time and generally consists of putting a sample in a glass bottle, shaking it, then letting

it settle for a certain amount of time, measuring the turbidity with a pipette or photometrically and relating it to the initial particle/aggregate size distribution (Middleton, 1930; Low, 1954; Williams et al., 1966). Extensions of the dispersion test are the "column tests", one of which is a permeability test requiring a vertical tube to be filled with aggregates of a predetermined size class, with water poured in the top (Low, 1954; Williams et al., 1966). The rate and extent to which the aggregates breakdown affects the column permeability which is an indication of aggregate stability. Another test called the Williams and Cooke slump test uses a similar column and aggregates but only measures the extent to which the column of aggregates slumps when wetted with water (Matkin and Smart, 1987). A third test, that can be called the Emerson dispersion test, is a series of steps, the first of which requires observation of 3-5 mm aggregates slaking in water (Emerson, 1977; Matkin and Smart, 1987). In the second step, non-slaked aggregates from step 1 are remoulded into 3-5 mm aggregates and immersed again. Finally (if carbonates or gypsum are not present) the remoulded material from step 2 that did not slake is made into a water-soil suspension and observations made if dispersion continues or flocculation occurs. The results allow soil aggregates to be classified into 6 classes.

One of the more recent methods of assessing aggregate stability is by ultrasonic dispersion where soil aggregates of predetermined size are exposed to ultrasonic sound at a given power for a given length of time and the resulting aggregate size distribution is analyzed (Imeson and Vis, 1984b). When analyzing a wide range of soils (from the standpoint of stability) the procedure must be adjusted and, overall, Imeson and Vis (1984b) found it provided no better an index of relative erodibility than waterdrop method indices.

2.3 Wet sieving

When examining the literature from the standpoint of aggregate stability and soil structure, one test method that has stood the test of time and is often used as a standard with which to compare other tests is the wet sieving method (Yoder, 1936, Gish and Browning, 1948; van Bavel, 1953; Low, 1954; Toogood and Lynch, 1959; Gupta, 1965; Kemper, 1965; Williams et al., 1966; Bryan, 1968; Baldock and Kay, 1987; Matkin and Smart, 1987). The original procedure was established in 1936 by R. E. Yoder and consisted of placing a soil sample on the top of a stack of 6 sieves arranged in decreasing size (5 to 0.1 mm) and gently moving the sieve stack up and down while immersed in water. The final aggregate distribution was the result of the slaking action on the air-dry sample and the forces of the moving water and collision with particles that became suspended in the water. With any sieving, dry or wet, if there is little energy input (e.g. movement) the result is an 'aggregate distribution' but, if there is more energy input such as prolonged dry sieving, sieving with tumblers, heat of wetting or moving water, the result is more an index of 'aggregate stability'. Although most researchers refer to wet sieving as a method of measuring aggregate stability, Kemper and Chepil (1965) listed the Yoder method under the chapter heading "Size Distribution of Aggregates" and not under "Aggregate Stability". Russell (1949) discussed the Yoder method under "aggregate size distribution" while under "aggregate stability" he discussed the waterdrop method and a single-screen wet sieving technique. Usually where a researcher wants an aggregate size distribution of a sample, a dry sieving technique is utilized as it is faster, requires less equipment and the sample does not undergo the forces of wetting (e.g. Baldock and Kay, 1987). The basic wet sieving method as put forward by Yoder has changed little in the past 50 years with the exception of sieve sizes and pretreatments (see Table 1).

The aim in the sizing of the sieves is to have the size decrease by one half from sieve to sieve from a range of about 4 mm to 0.1 mm. As can be seen in Table 1 this is usually

the case. The sample to be introduced is hand sieved with a 8 mm sieve so that it is double the first sieve size at the start of sieving (van Bavel, 1953; Kemper and Chepil, 1965). An exception to this is that by Toogood and Lynch (1959) which hand sieved with a 4 mm sieve and then pushed the sample through that sieve at the start of sieving (no reasons were given). The size of the bottom screen is variable due to a compromise between aggregate distribution and aggregate stability. The more screens present and the smaller they are, the greater the damping effect on water movement (Conway and Strickling, 1962). This assumes water movement plays a major role in aggregate stability over and above that of slaking. Sometimes the smallest screen chosen is 0.25 or 0.5 mm to minimize the damping effect of water flow and yet leave enough sieves in the stack to generate aggregate stability indices comparable to those of other workers (e.g. Williams et al., 1966; Bryan, 1968). More substantial departures from the Yoder method involve the isolation of a certain aggregate size fraction and then wet sieving it on one or two sieves noting the percentage change. Low (1954) hand sieved samples to retain the 3 to 5 mm fraction, then wet sieved them on 2 sieves (2 and 0.5 mm), and expressed the results as "percent of soil <2 mm in water stable aggregates >2 mm". The use of a stack of several sieves allows one a choice of aggregate indices such as "percentage greater than", "percent between a certain size range", or "mean weight diameter".

Pretreatments of aggregates are numerous. They can be immersed in an air dry condition or wetted to varying degrees under tension or in a vacuum. Most workers adopted the immersion of air dry aggregates as this causes the maximum breakdown due to slaking, closely resembles natural conditions, is considered to be the most suitable technique for erosion studies, and the results provide the best separation of soils (Yoder, 1936; van Bavel, 1953; Low, 1954; Kemper, 1965; Williams et al., 1966; Bryan, 1968).

2.4 Waterdrop method

T. M. McCalla (1944) is credited by many researchers with the origin of the waterdrop method. Since that time various versions of the method have appeared (see Table 2), although the main form remains the same. The method essentially consists of waterdrops falling a predetermined distance to impact with an aggregate ultimately breaking it down.

Water temperature has an effect on the number of drops required for aggregate disintegration. McCalla (1944) found that as water temperature increased from 0 to 60 °C the number of drops to disintegration decreased 17% and 31% on two different soils. Bruce-Okine and Lal (1975) found that with a water temperature increase from 30 to 50 °C the number of drops to disintegration decreased 40-86% over the soils tested at a pF of 4.44. For aggregates at pF 7.0 the trend was the same, but smaller, being in the range of a 53-74% decrease. In examining wet sieving procedures Low (1954) found a linear decrease in aggregate stability over a water temperature range of 5 to 50 °C. The decrease was about 40% and 120% for the two soils tested. McCalla (1944) and Bruce-Okine and Lal (1975) both recommended room temperatures for water indicating that as well as being convenient, minor temperature fluctuations did not influence the results. Other researchers using the method did not stipulate water temperatures and when apparatus diagrams are shown it appears there is no water temperature regulation. Water quality does not appear to unduly influence test results as well. Most of the time no mention was made of it with the exception of Farres and Cousen (1985) who stated that deionized water buffered to pH 5.6 (pH in equilibrium with atmosphere) was the "optimum chemistry".

Drop size and height of fall vary from test to test within the constraints of the dimensions of a normal laboratory and droplet sizes found in rainfall. The height of fall is usually in the 0.5 to 2.0 m range although it appears a height of 1.0 m is common (Table

2). The range in droplet size selected was a function of fall height and aggregate size. If the aggregates to be tested are small, the droplet selected is correspondingly small so the impact perimeter is no larger than the aggregate. If the height of fall is small, the droplet selected is usually large so that the kinetic energy may be similar to smaller drops falling larger distances. Overall the droplet sizes appear to be somewhat larger than natural rainfall. Even though the droplets do not reach terminal velocities in the fall heights used, the droplet kinetic energy may be similar to natural rainfall. It appears that median drop diameter for temperate climate storms averages approximately 2-3 mm depending on storm intensity (Hudson, 1981). McCalla (1944) found as drop size increased, number of drops to aggregate breakdown decreased. Wustamidin et al. (1983) noted the same but when the data were converted to energy required for aggregate breakdown, the differences between drop sizes were not significant. McCalla (1944) found little difference in using drop heights from 5 to 150 cm although a slight decrease in the number of drops required was observed when the height was increased from 5 to 30 cm. Ghadiri and Payne (1977) showed a decreasing number of drops to aggregate breakdown are required when height of fall increased from 0.5 to 6.0 m. The relationship was gently curvilinear. A decrease in the variance of average drops to aggregate breakdown was observed with increasing height of fall by Farres and Cousen (1985) who recommended a fall height of 2 m which would minimize the variance and could be easily attainable in common laboratories.

A drop frequency of about 1 per second is common, more from the standpoint of consistency of method and convenience than anything else. Farres and Cousen (1985) recommended a rate of 110 drops/min (1.8 drops/s) without giving any reason. It should be noted, however, that they used an electronic method of counting drops. McCalla (1944) and Smith and Cernuda (1951) were the only researchers who tested various drop frequencies and found conflicting results. McCalla (1944) found no significant differences in drops required for breakdown due to an increase in drop frequency from one per 36 s to

one per 0.55 s when working on a subsoil, but did find an increase in drops required for a topsoil sample. Smith and Cernuda (1951) found a decrease in drops required with increasing frequency when working with subsoils. They found that aggregate breakdown was more a function of time wetted than number of drops; thus, discounting any role of kinetic energy. The aggregates used by McCalla were 0.15 g in size compared to the 1 g aggregates used by Smith and Cernuda and thus would have wetted much quicker.

Aggregate size appears to be a matter of preference and/or a match with the waterdrop dimension (the idea being for the diameter of the droplet to be the same or smaller than the aggregate for the maximum transfer of energy). Size has ranged from 0.15 g (McCalla, 1944) to almost 4 g (Bruce-Okine and Lal, 1975). McCalla (1944) tested aggregates from 0.05 to 0.25 g in size and found less variation in drop requirements for larger aggregates and chose 0.15 g as his standard. Bruce-Okine and Lal (1975), working in Nigeria, found surface soil aggregates (at 0% RH) ranging from 1.25 to 3.45 g did not significantly affect the number of drops required for breakdown. Results from Australia on aggregates 0.1 to 0.2 g agree with this (Wustamidin et al., 1983). Smith and Cernuda (1951) only used 1.0 g aggregates (6-13 mm diameter) observing it was a size appropriate for testing earthworm casts and remoulded aggregates, and cited research indicating they were the largest unit usually desirable in cultivated soils. Farres and Cousen (1985) working in England stated that aggregate size should give the best representation of the soil being tested (ie. the median range of the bulk sample) and chose a 4-6 mm size for the five soil types they tested.

Prewetting of aggregates has a significant but not consistent effect on their stability to waterdrop impact. McCalla (1944) found a slight decrease in the number of drops required to break down prewetted aggregates (placed on saturated cheesecloth for 15 min). Smith and Cernuda (1951) found aggregates wetted under vacuum were more resistant to drops than aggregates wetted in the normal atmosphere. Bruce-Okine and Lal (1975) found that

dry aggregates of a tropical expanding clay soil broke down quicker than slightly moist ones while a kaolinitic sandy clay loam was more stable in a drier condition. Bergsma and Valenzuela (1981) working with Spanish soils found that the stability of the air-dry soils was the greatest, decreasing 30-300% upon prewetting (1-24 h on filter paper over sand with water level 5 cm below). The stability recovered somewhat as prewetting time increased from 1 to 24 hours. They also found that while dry stability increased with profile depth, once the aggregates were prewetted the trend was reversed. Cousen and Farres (1984) worked with a temperate coarse textured surface soil (73% sand, 17% silt) at varying moisture contents and found greater stability and greater variance of data at low moisture contents. Variance and stability decreased rapidly as moisture increased to about 20% (gravimetric). This led them to recommend a gravimetric moisture level of 25% (Farres and Cousen, 1985) as a constant for the test. While that may prove advantageous for one type of soil, it has been shown that changes in aggregate stability with changes in water content are not consistent across types of soils (Bruce-Okine and Lal, 1975; Bergsma and Valenzuela, 1981).

The waterdrop method does appear to have gained acceptance as a method of measuring aggregate stability as evidenced by the number of researchers currently using it (Imeson and Jungeruis, 1976; DeMeester and Jungeruis, 1978; Bergsma and Valenzuela, 1981; Bryan and Luk, 1981; Lindsay and Gumbs, 1982; Wustamidin et al., 1983) and suggestions for a more definite standardization have been put forward (Farres and Cousen, 1985). It is noted that the method appears more often in the European literature and is used often in comparisons of surface with subsurface soils and in comparison of cropping treatments but not on comparisons of different soils with the same treatment.

2.5 The Universal Soil Loss Equation

A glance at the soils literature indicates soil conservation efforts have been most evident in the U.S.A. since the early part of the 20th century and have gained popularity and momentum since World War II. As scientists studied erosion to understand the processes involved, they were able to establish some factors common to all cultivated soils that would predispose them to accelerated erosion. In an attempt to predict erosion, scientists combined factors to form predictive equations for soil erosion. Several researchers in the 1940s put forward predictive equations based on topography, climate, cropping, and conservation practices (Zingg, 1940; Musgrave, 1947; Wischmeier and Smith, 1978). With the establishment of a National Runoff and Soil Loss Data Center at Purdue University in 1954, work on improving and applying existing equations continued and resulted in an equation called the Universal Soil Loss Equation (USLE) under the main influence of W. H. Wischmeier and D. D. Smith (Wischmeier, 1959; Wischmeier and Smith, 1978; Hudson, 1981). The USLE is commonly presented in the following form (Wischmeier and Smith, 1978):

A = R K L S C P

where:

A = the soil loss per unit area.

R = the rainfall and runoff factor. Historically the cumulative energy of rainfall; now it usually includes a snowmelt runoff factor where appropriate.

K = the soil erodibility factor. The soil loss rate per erosion index unit for a specified soil as measured on a unit plot (the statistically average plot from over 10,000 plot-years of data).

L = the length of slope factor. The ratio of soil loss from a field slope length to that from a unit plot length (22.6 m) under identical conditions.

S = the steepness of slope factor. The ratio of soil loss from a field slope gradient to that of a unit plot (9%) under identical conditions.

C = the cover and management factor. The ratio of soil loss from an area with specified crop cover and management (e.g. plant species and planted population) to that of an identical area in tilled continuous fallow.

P = the support/conservation practice factor. The ratio of soil loss with a support practice like contouring or terracing to that with straight-row farming up and down the slope.

The dimensions and metric units of the USLE are (Foster et al., 1981):

USLE Factor	Dimensions*	Units
A	M/L^2T	t/ha
R (=EI)	LFL/L^2T	(MJ mm)/(ha h yr)
K	ML^2T/L^2LFL	(t ha h)/(ha MJ mm)
L	$(L/L)^m$	
S	dimensionless	
C	dimensionless	
P	dimensionless	

* L=length, M=mass, T=time, F=force, m = exponent from 0.2 to 0.5

The basic equation can be expressed as A = R x K since erosion is a function of rainfall erosivity (or climatic erosivity in a larger sense) and soil erodibility which are in turn modified by the remaining factors of crop, slopes, management, etc. (Hudson, 1981).

The USLE is an empirical equation derived from plot data predominantly from the southeastern and midwestern U.S.A. Applying it to very different geographical areas (e.g. Africa or perhaps, the Canadian prairies) or situations for which it was not designed (e.g. watershed sediment yields) requires a validation of variables from local data (Wischmeier, 1976). The USLE will only predict soil loss on an average annual basis for specified field conditions. It estimates only sheet and rill erosion, not gully erosion or soil deposition within a field (Wischmeier, 1976). Regardless of the limitations of the USLE, it has become the most widely used and accepted method of predicting potential soil losses on an annual basis (Hudson, 1981). A U.S.A. court of law has recognized that the USLE can

provide proof of present actual soil loss to satisfy the claim of excessive erosion (Coughlin, 1984).

The USLE was applied only to specific sites in Canada up to the 1970s (Ketcheson, 1977) with no large scale mapping of the USLE variables until the late 1970s. Van Vliet et al. (1976) published an isoerodent (lines of equal R) map for southern Ontario and Wall et al. (1983) published one for the prairies. Kachanoski and de Jong (1985) disputed the method of predicting the R factor by Wall et al. (1983) and found the actual value to be 340 versus the predicted of 850 for Saskatoon. Subsequently the R factor has been revised to include the influence of winter precipitation and snowmelt (which the original R factor did not consider) and a provincial scale map has been produced for Alberta (Tajek et al., 1985). Variability in the R factor is still present depending on the prediction method used. For the Edmonton area Tajek et al. (1985) predicted an R value of 644 (including a winter R prediction). If one uses the method of Kachanoski and de Jong (1985), which closely approximated the actual for Saskatoon, a R value of 342 for Edmonton is obtained.

Little attempt has been made to verify the individual factors of the USLE for Canadian conditions with the exception of the R factor. The weaknesses of the USLE in predicting erosion outside of North America has been recognized and the R factor has been altered to suit different conditions (Arnoldus, 1980; Hudson, 1981). It is the prevalent opinion of European researchers that the R and K factors cannot be applied to European conditions without extensive modifications (de Ploey and Ahnert, 1985). The R and K factors of the USLE are related and dependent on one another (Foster et al., 1982; Laflen, 1982). Thus for a given soil loss, A, and the modifying factors L, S, C, and P remaining constant, if R is changed/modified then K must be altered to maintain the value of A. The equation is often rearranged to solve for any one of the variables however changing the value of one factor will affect the other (assuming a constant erosion rate).

The factor K is the soil erodibility factor, defined by Wischmeier and Smith (1978) as the rate of soil loss per erosion index unit (R) as measured on a "unit plot" (continuous fallow plot 22.3 m long, tilled up and down a 9% slope). When a "unit plot" condition is met, the factors L, S, C, and P all equal 1.0 so K is equal to A/R. Original long term plots established at several research centres in the corn belt and southeastern U.S.A. provided reliable soil loss data to calculate K, but this proved to be very time consuming and costly so another method was needed to establish erodibility values for a wide range of soils. In order to be able to calculate a K value from other soil factors research started in 1961 on 55 soils in the corn belt using rainfall simulators (Wischmeier and Mannering, 1969). The rainfall simulators delivered a constant intensity of rainfall so 4 storm durations were imposed for four R values. The test sites were medium textured (sandy loam to silty clay) soils with 0.9 to 5.5% organic matter located on farm fields that had been in row crops for 3 years. Crop residue was removed in the spring and rainulator tests were conducted in mid-summer after the field had been worked several times. Linear regression equations were derived from measured soil chemical and physical properties that explained 95% of the variation in soil loss from the plots for each rainstorm size. Through the use of expected averages of time-dependent variables, the equations could be solved for soil loss under "unit plot" conditions. Linear regression of soil loss on the 4 rainstorm energies (R) gave a line for which the slope was equal to the K values for each of the 55 sites (it is evident that the method of calculating the R factor will affect the K value obtained). Multiple linear regression techniques using 24 variables, representing 15 soil properties and their interactions, yielded an equation that explained 98% of the variance in the plotted K values. Recognizing that the equation was cumbersome for widespread use, Wischmeier et al. (1971), using the data and equations of Wischmeier and Mannering (1969), generated a nomograph to calculate K for farmland and construction sites. The nomograph is shown in Figure 1. Wischmeier and Smith (1978) provided the equation for the nomograph as :

$$K = 2.1M^{1.14}(10^{-4})\ (12-a) + 3.25(b-2) + 2.5(c-3)$$

where:
M = particle size parameter = (%silt+very fine sand) (100-%clay)
a = % organic matter
b = soil structure code used in soil classification
c = profile permeability class

Wischmeier et al. (1971) indicated that 68% of the K values calculated using the nomograph should be within 6.4% of the true values, 90% within 11% of the true values. Wischmeier and Mannering (1971) stated that their equations were not valid for soils with more than 65% sand or 35% clay. In comparing nomograph, regression (after a method by Wischmeier) and observed plot values for K, Laflen (1982) found substantial differences in the methods on 2 of 4 soils studied. Laflen (1982) reported other plot studies to verify K values in Minnesota where nomograph K values were substantially different than measured in 8 of the 13 soils studied.

Finally, it should be noted that although Laflen (1982) in his critical examination of K stated that it is difficult to agree that the K value is a "good" estimate of soil erodibility, but relative to the quality of the other variables in the USLE, the quality of the K variable might be "good". Additionally, it should be noted that Wischmeier and Smith (1978) stated K is an average value for a soil and direct measurements of it require soil loss measurements for a representative range of storm sizes and antecedent soil conditions. Wischmeier (1976) called the application of the ULSE to situations where its factor values cannot be determined from existing data with acceptable accuracy a misuse of the equation.

Since there is an increasing desire in Canada to quantify and predict erosional losses and the USLE is a proven, popular, and acceptable equation for prediction of potential average annual losses, it seems appropriate to apply it to Canadian conditions. However, in many parts of Canada, especially the prairies, climatic and soil conditions are quite

different from those under which the USLE was derived and applying it to some Canadian conditions may be extrapolating its use beyond the conditions for which it was derived. Additionally, some of the factors such as the R and K factor require either long term or detailed data. Since it is highly unlikely that long term plot data will be generated to establish K values for various soils, the nomograph method is the only alternative at present to determine soil erodibility for the USLE. With respect to the data required to estimate K from the nomograph, most of the data needs to be generated by a soils laboratory, the particle size divisions are not the normal divisions used by Canadian soils laboratories, and the organic matter content of many Canadian soils are beyond the limits of the nomograph. With variable soil conditions and types often occurring within a farm field, several groups of analyses would be required to develop a complete estimate of soil movement on a field scale. This makes the USLE less appealing for farm conservation use in Canada.

Weaknesses are apparent in using the nomograph estimation of the USLE soil erodibility factor and an alternative method would be desirable from several standpoints. Rainfall erosion commences with raindrop impact on the soil surface which closely resembles the action of the waterdrop method of aggregate stability assessment. The waterdrop method appears simple, unsophisticated, quick, and easy to use and, if the method could be utilized in some way to estimate the USLE K factor, it would provide a more accurate estimate of erodibility than currently exists using the nomograph method. With this goal a study was undertaken with the objectives of (1) to investigate if any correlations exist between the waterdrop method and the nomograph-predicted K factor of the USLE such that the waterdrop method can provide an acceptable predictor of K and, (2) to examine some of the soil factors affecting the waterdrop method and, observe any relations between the waterdrop method and wet sieving results.

3.0 MATERIALS AND METHODS

3.1 Sampling

3.1.1 Fields

Fields throughout central Alberta ranging from Two Hills to Hanna in a north-south direction and from that line to Rocky Mountain House in the west were chosen for sampling (see Figure 2). The criteria used for choosing a field to sample were:

1. The field was under cultivation and had been for at least ten years.
2. The field had a finite slope >2% (i.e. water erosion could occur on it).
3. The field was continuously cropped or was in the last year of crop before summerfallow.
4. The field had undergone spring cultivation.
5. The field was located in an area where the desired soil series dominated the landscape as determined from soil surveys.

3.1.2 Soils

To ensure that a broad range of soils was represented, 20 soil series were chosen ranging from erosion classes 1 to 6 as determined by Tajek et al. (1985). Tajek et al. (1985) did not give the class boundaries but they appear to be equally split along the range of K values determined, with erosion class 1 the least erodible. A summary of the soils chosen is given in Table 3. The 20 soil series sampled were from the Chernozemic, Luvisolic, and Solonetzic orders and ranged widely in properties. Three fields of each series were chosen for sampling. The three fields were not necessarily in the same area (i.e. they could be from two different counties). A total of 64 fields was sampled including one field sampled in error (sample 26). Thus, the initial data set consisted of 63 cases. In the analysis of the wet sieving data it was discovered that a few samples generated

inaccurate results due to puddling/sealing on the sieves. Thus, the data set was reduced to 56 cases. The 8 samples deleted were Samples 18, 20, 22, 24, 32, 47, and 48. No consistency in properties were noted for the eight samples. They ranged in texture from clay to loamy sand, in organic matter from 13 to 3%, and in classification from Orthic Black to Orthic Gray Luvisol. This smaller data set (56) was used for examination of wet sieving and relationships between wet sieving and other variables. The complete data set (63) was used for discussion of the USLE K value and the waterdrop indices.

3.1.3 Samples

Composite samples of the surface 2 cm were taken from a field using a metal, flat-bottomed scoop 15 cm wide and 6 cm deep with a 1 cm wide dotted line painted on the inside at the 2 to 3 cm depth. A representative area of each field was sampled to a 3 cm depth with the scoop approximately every 10 paces until about 10 litres were collected in a plastic pail. All fields were sampled between May 19 and June 13, 1986. Weather conditions throughout the sampling period were warm (daytime highs in the low to mid 20 °C range) with slight breezes and no significant precipitation (the spring was classified by farmers as a "dry spring"). All soils were dry at sampling time.

Samples were stored in plastic pails until a few days prior to wet sieving when they were poured into wooden trays 60 cm square and 9 cm deep. Samples were thoroughly mixed by hand and a composite sub sample taken from the tray with a small scoop and hand sieved to pass an 8 mm sieve. A 50 g sample was then taken from the sub-sample for wet sieving. At the same time, aggregates appearing to be 1 g in size (7-13 mm) were collected from the sample in the wooden tray for the waterdrop method. Another composite bulk sample was taken from the wooden tray, ground to pass a 2 mm sieve and used for particle size, pH and carbonate analysis. A sub-sample of the 2 mm sample was taken and ground through a 100 mesh sieve (0.25 mm) for organic carbon determination.

3.2 Analyses

3.2.1 Particle size analysis

The hydrometer method as outlined by McKeague (1978) was used for particle size analysis with readings at 0.5 min., 1.0 min. and 12 h. Samples were dispersed with sodium hexametaphosphate and those with greater than 4.25% organic matter were pretreated with hydrogen peroxide. The range of particle sizes of the samples is given in Figure 3.

3.2.2 Organic matter

Total carbon was determined by CO_2 evolution in a combustion furnace. The soil sample was finely ground in a Siebtechnik Laboratory disk mill prior to dry combustion in a Leco Carbon Determinator Model CR12. Inorganic carbon was determined on samples that effervesced with 10% HCl and/or had a pH greater than 7.0. The pH was determined in a 1:2 soil:water suspension using a Fischer Acumet Model 630 pH meter standardized in buffer solutions at pH 4 and pH 7. Inorganic carbon was determined by titration of KOH (+CO_2) with HCl to the phenolphthalein end point after the method of Bundy and Bremner (1972) as modified by Yee (1987). Organic carbon was then determined by difference (total C - inorganic C). Organic matter was calculated by multiplying organic carbon by 1.724 (Nelson and Sommers, 1982).

3.2.3 Wet Sieving

The apparatus and procedure outlined by Yoder (1936) was used with some modifications. The apparatus consisted of three metal cannisters into which, suspended from an arm, was a clamped stack of 6 sieves, 18 cm in diameter. The sieve sizes were 4, 2, 1, 0.5, 0.25, and 0.125 mm. The arm driven by an electric motor, pivoted up and down with a 4 cm stroke at 30 cycles per minute. Enough water (at 21±1 °C) was poured into

the drums to cover the top sieve at the bottom of the stroke. The stack of sieves was then lowered into the water and fixed to the arm ensuring the top sieve did not become wet. Tap water was used. Electrical conductivity measured every few weeks ranged from 23 to 35 mS m^{-1}. The laboratory temperature was approximately 20 °C with an average relative humidity of 46%.

Several (10-20) small sub-samples were taken from the wooden tray and gently shaken through a 8.0 mm sieve into a bowl. Three 50 g sub-samples were taken from the bowl for wet sieving and a 20 g sample for moisture determination (to convert sieving data to oven dry weights). The 50 g sub-samples were then gently poured on the top sieve of the sieving stack and the stack lowered so the top sieve was covered with water. After 1 minute the motor was started and sieving ceased after 30 minutes. The sample remaining on each sieve was oven dried (105 °C) and sand corrections made. Sand corrections for the 4 and 2 mm sieves were made by dispersing (0.5N sodium hexametaphosphate) each sample and resieving by hand. Sand corrections of the 1.0 through 0.125 mm sieves were done with a Bradley Sonic Sifter containing the same sized sieves as the wet sieving apparatus.

The results of the 3 sub samples were averaged to produce the raw data to calculate mean weight diameters for each sample. Mean weight diameter as defined by van Bavel (1949) was calculated after a method described by Youker and McGuinness (1956) using a computer program (Appendix A). The percentage of sample retained on each sieve was also used to develop several other variables: the percent larger than 2 mm, percent larger than 0.5 mm and the percent between 0.5 and 2 mm in diameter.

Initially, the sample size selected for wet sieving was 60 g as recommended by Toogood (1975). However, regardless of careful distribution of the sample over the top sieves, sealing occurred on one of the lowest 2 or 3 sieves. Samples were rerun with 50 g

samples without obvious sealing occurring. It was desirable to have as large a sample as possible to minimize measurement errors in the assessment of the portion of soil retained on individual sieves. Nevertheless, in correcting the initial sieve weights for sand weights to obtain a weight due to aggregates, it was found that negative numbers were obtained for some samples for the 0.125 mm sieves indicating that some of the soil was retained in the previous sieve due to sealing. These samples were deleted from the data set for analysis of wet sieving data and comparisons with waterdrop and/or K value data (new data set had 56 observations). Furthermore, it was felt the 0.125 mm sieve did not contribute greatly to a calculation of an aggregation index and possibly did not result in a true separation of some samples so, calculation of any index such as the mean weight diameter was done with the results of the five largest sieves.

3.2.4 Waterdrop Method

Aggregates approximately 1 g in size (7-13 mm in diameter) were selected at random from the surface of a soil sample placed in a 60 cm X 60 cm tray. The aggregates were then weighed and shaved or picked with a penknife to a weight of 1.0±0.2 g. Forty aggregates from each sample were subjected to waterdrops.

The waterdrop apparatus consisted of a constant head apparatus connected to the cold water supply. The constant head apparatus fed a 250 ml separatory funnel. The funnel nozzle was fitted with a reducer which was the tip portion from a 3 ml plastic syringe. On this, the drop former was placed; a 15 mm long piece of Tygon tubing with a 3 mm inside diameter and the free end cut at a 45° angle.

The drop size was measured by three replications of collecting 10 drops in a pan and weighing immediately. This yielded a drop mass of 0.069 g and assuming a spherical drop, a diameter of 5.09 mm was calculated. The height of fall to the aggregate was 1.5

m. Epema and Riezebos (1983) found that a 5.0 mm drop falling 1.5 m has an impact velocity of 5.08 m s^{-1}. Thus the kinetic energy of a single drop was 8.9 X 10^{-4} J.

Aggregates were placed on a 20 cm diameter, 3.35 mm sieve (Tyler no. 6 mesh) that was placed on a ceramic evaporating dish (22 cm diameter). Waterdrops fell onto the aggregate at a rate of 1 per second. The endpoint was the point at which the aggregate and/or parts of it passed through the 3.35 mm sieve. Waterdrops were not counted past 150.

During the waterdrop testing the tap water was tested for electrical conductivity 5 times with a resulting range of 23-35 mS m^{-1}. The water temperature in the waterdrop apparatus was 20±2 °C. Relative humidity of the laboratory measured 14 times with a sling psychrometer was an average of 46% (s.d.=17%). Room temperature was 20±2 °C.

When compared with wet sieving of soil, the waterdrop method required less equipment and less time to complete analysis of a sample. The waterdrop apparatus was constructed from easily available materials, took about a meter of bench space, and the time required from initial aggregate collection to raw number results was approximately 45 minutes for one sample.

The variability of composite soil samples observed in initial testing indicated a large number of observations was needed on a sample. Thus, 40 aggregates approximately 1 g in mass were taken from each soil sample and subjected to the waterdrops. Two parameters were developed for the waterdrop method. One consisted of the mean waterdrop count of the 40 aggregates (WD1) and the other (WD2) was the mean waterdrop count of 30 aggregates after the greatest outliers had been removed from WD1. The WD2 parameter avoided the influence of extraordinary aggregates such as ones with cores of stones or containing fibrous roots. To monitor the variability in a sample, the coefficient of variation was calculated for WD1 and WD2 (CV1 and CV2). The

coefficient of variation weights the variance of the measurement according to the mean and is calculated as 100s/x where s is the standard deviation and x is the sample mean (Steel and Torrie, 1980). Knowing the drop interval (1 second) and the individual drop energy (8.9×10^{-4} J) the WD1 and WD2 parameters could be converted to "time to aggregate failure" or, "energy for aggregate failure".

3.2.5 USLE-K factor

The soil erodibility factor, K of the U.S.L.E. was originally developed from long term plot data and is the soil loss rate (from a "unit plot") per erosion index unit as stated in the preceding literature review. The lack of long term plot data on the large number of different soils in the U.S.A. presented the problem of how to estimate the K factor for different soils.

The equation for the nomograph was presented in 1978 (Wischmeier and Smith, 1978) as:

$$K = 2.1M^{1.14}(10^{-4})\ (12-a) + 3.25(b-2) + 2.5(c-3)$$

where:

M = particle size parameter = (%silt+very fine sand)(100-%clay)
a = % organic matter
b = soil structure code used in soil classification
c = profile permeability class

The nomograph appears in Figure 1. Note the first product of the equation [$2.1M^{1.14}(10^{-4})$ (12-a)] and nomograph require quantitative information whereas the second and third products (structure and permeability) are qualitative ranking. If structure and permeability are rated in the middle of their scales, "fine granular and moderate" respectively, the last two products of the equation go to zero (b=2, c=3). No guidelines for ranking these two factors have been presented (Wischmeier and Smith, 1978) other

than a referral to the Soil Survey Manual of the USDA which only elaborates in a subjective manner. Therefore, structure and permeability are not differentiated by a numerically measured characteristic but rather, class ranked accorrding to visual evaluations.

K values were calculated in Imperial units according to the nomograph formula then converted to SI by multiplying by 0.1317 (Foster et al., 1981). The SI units of K are then t*ha*h/ha*MJ*mm. It is noted that the hectare unit in both numerator and denomenator will cancel out but are left to indicate that the K value is the soil loss per unit area per unit of R.

One of the inherent problems of using the USLE is the determination of the K value when actual plot data is not available. Often the USDA handbook No. 282 (Wischmeier and Smith, 1978) is used and the K value determined from the nomograph. The nomograph technique allows a range of organic matter levels from 0 to 4%. It is observed in the equation for calculating K that a maximum level of 12% organic matter can be tolerated before a negative K value is produced (and ultimately a negative soil loss value). The soils on which the equation was derived had a maximum organic matter level of 5.5%. Empirical equations and nomographs are considered to be less accurate the more they are extrapolated beyond their limits. Many Canadian soils however have organic matter levels greater than 4% and some are more than 12%. Of the soils in the present study 48 (76% of the samples) had greater than 4% organic matter and 2 had more than 12% organic matter. Clearly some extrapolation of the nomograph must be conducted for use of the USLE in Canada. Tajek et al. (1985) used the USLE for their estimation of water erosion potential in Alberta. They used a modified R factor and grouped all Alberta soils into 4 organic matter classes. The organic matter levels reported for class separation by Tajek et al. (1985) were actually organic carbon levels (Pettapiece,

1988). Thus the numbers were multiplied by 1.724 to convert to organic matter as follows:

Brown and Gray Luvisol soil zones	3.4% organic matter
Dark Brown and Dark Gray Luvisol soil zones	5.2% organic matter
Black soil zone	6.9% organic matter
Humic Gleysols	8.6% organic matter

Thus, organic matter content measurements were not needed but extrapolation of the nomograph to 8.6% organic matter would have been required. Campbell et al. (1986) reported average organic matter contents for prairie Brown, Dark Brown and Black soil zones as 2%, 4%, and 7% respectively. It should be noted in the Chernozemic order soils have organic matter levels between 1 and 17%. Vold et al. (1985) in mapping erosion potential of the lower Fraser valley in B. C, used the 4% organic matter curve for all soils greater than 4% organic matter. This was recommended by USDA - SCS staff in Washington state as the procedure to be used for soils in excess of 4% organic matter. Voroney et al. (1981) studied organic carbon dynamics on a Black Chernozemic soil in Saskatchewan with surface organic matter levels ranging from 5 to 11% organic matter. In simulation of erosion on the same soil using the USLE, Voroney et al. (1981) used the nomograph equation setting K at 0.8 if organic matter content was zero and noted that K decreased linearly to 0 as organic matter increased (above 7%).

In the present study, when K values were calculated using the predictive equation restricting organic matter levels at 4% ('K4') and the result graphed against the actual sample organic matter levels, a poor trend developed (Figure 4). This relationship had less scatter when organic matter levels were not restricted (Figure 5). When the two methods of calculating K are plotted against one another a great deal of dispersion is observed for at least half the data set (Figure 6). It should be noted that 2 samples with

organic matter levels exceeding 12% generated negative K values (Figure 5). For purposes of the present study the negative values were accepted in order to allow a trend to continue to the extreme, however, it is recognized that the figures would have to be set at <12% organic matter in order to be inserted into the USLE to prevent a negative soil loss value. Since Wischmeier et al. (1971) found organic matter to be the second most important soil factor related to erosion after texture, the determination of K should be allowed over a wide range of organic matter levels.

It is noted that the USLE nomograph was derived over a narrower textural range of soils than those presented here. Wischmeier and Mannering (1969) stated that their sampling of soils with >65% sand or >35% clay was inadequate to use the equation for K with confidence (35 of their 55 soils were silt loams). The data set of 63 cases would be reduced to 50 cases if the >65% sand and >35% clay restriction was imposed. It is felt however, that using the complete 63 case data set would indicate further weaknesses or strengths of the USLE - K calculation and indicate the relationships of the textural variables in the extreme regions.

The soil erodibility factor, K, of the USLE was calculated for the current study using the nomograph formula as presented by Wischmeier and Smith (1978) and outlined above except that permeability and structure were not included. Thus, the K values calculated were the first approximation of K. The nomograph formula requires the sum of the very fine sand and silt fraction. The sand corrections for wet sieving gave a very fine sand fraction which was added to the silt fraction determined from the particle size analysis.

3.4 Statistics

Regression analysis was used on the data. Initial data manipulation and elementary statistics were done with Microsoft Excel spreadsheet software. Regression analysis,

correlations, nonlinear analysis and some statistics were done with SYSTAT statistical software (Wilkinson, 1986). Regression was by forward stepwise, least squares simple linear and multiple analysis. Variables and residuals were examined for normality by histograms, probability plots, and skewness statistics. Plots of residuals versus predicted variables and some independent variables were conducted to ensure conformity to assumptions (normality, linearity, homocedasticity). Each variable in the data sets was transformed as required to conform to normal distributions and/or corrections for normality of residual distributions in regression analysis. In some cases variables were coded to accommodate transformations or to remove excessive zeros in regression coefficients. Pearson product-moment correlations were used. The SAS (version 6.03) modules glm (general linear model for unequal observations) and LSMeans (t-test) were used for post hoc contrasts between groups created for series, erosion classes, and textural classes. Probabilities are stated wherever possible but in some instances the following notation is used: * for $p<0.05$, ** for $p<0.01$, *** for $p<0.001$. Table 4 lists the variables used, their description and transformations.

4.0 RESULTS AND DISCUSSION

4.1 K value

Four statistics for the calculated K values (converted to SI units) are as follows:

	K	K4
Minimum	-0.005	0.007
Maximum	0.057	0.057
Range	0.062	0.050
Mean	0.021	0.028

Pearson simple correlation coefficients for the parameters used to calculate the first approximation of K as well as the sand contents are presented in Table 5 for the complete data set. As expected, K is significantly correlated with the variables used in the nomograph. For K4 the highest correlation was with SVFS followed by SILT and LCLAY. After the textural variables, K4 was correlated with LOM. These findings are in accordance with the original derivation of the K nomograph where Wischmeier et al. (1971) found organic matter to be the next most important factor after the textural variable. With respect to correlations with K, the most significant was LOM followed by SVFS, LCLAY and SILT in that order (Table 5). This indicates a reversal of the priority, or importance, of the textural variables and organic matter with K. It may not be an unreasonable reversal, however, since organic matter was found to be important in reducing erodibility by Wischmeier et al. (1971) over the limited range they tested and thus, would likely continue to impart an influence on erodibility beyond that range. With the high organic matter levels measured in the current study (the mean value of organic matter was 6.4%) compared to that of Wischmeier et al. (1971), it seems plausible that it may be dominant over texture.

The K and K4 values were correlated similarly with the wet sieving variables (Table 6). The best correlation was with MM52 and the second best with MM5. The correlation

with LMM2 and LMWD were not significant. The correlations between K and K4, and the waterdrop variables were not significant. The best correlation obtained was between LWD1 and K, r=-0.222 (n=63) while K4 was much lower, r=-0.019.

4.2 Waterdrop Method

Five statistics for the waterdrop indices and their respective CVs are as follows (n=63 samples):

	WD1	CV1	WD2	CV2
minimum	27	12	24	6
maximum	114	70	97	49
range	87	58	72	43
mean	51	37	46	20
s.d.	21	15	18	10

Variability within a sample was not uncommon among the samples collected as exemplified by Sample 5, an Orthic Gray Luvisol of the Breton soil series found southwest of Edmonton. The Breton soil is noted for having a very light coloured Ae horizon called a "foaming Ae" due to its characteristics upon wetting. A small proportion of the surface (≤5%) had clods and aggregates of relatively pure Ae material. The lighter material was 10YR8/3 in colour while the darker soil was 10YR5/2. The darker material had a WD1 of 42.8 (CV was 34%) and a WD2 of 38.8 (CV = 20%) while 11 aggregates of relatively pure Ae found at the surface had a mean WD of 21.5 (CV = 16%). Analysis of a ground sample or a sample of the dominant soil in a field does not acknowledge (or measure) the extremes of variability in soil properties which may be important. The portions of exposed Ae material in sample 5 could influence surface sealing by rainfall in a manner not predicted by analysis of the bulk soil.

The waterdrop test also revealed the variation in aggregate response to wetting. The Orthic Dark Brown clay soils (55% clay) of the Drumheller series showed noticeable and

dramatic swelling within the initial few seconds of wetting yet complete disruption to the point of passing the 3.35 mm sieve was not achieved until approximately 30 seconds (30 drops) had elapsed.

The variance in the waterdrop test results increased with an increasing WD value (Figure 7). There was a general trend of increasing waterdrops with clay content (Figure 8) except with the notable existence of a couple of clusters. One is a group of four points with high clay contents and low waterdrop counts. This group consists of the three Drumheller series samples and one Malmo series (sample 33). The Malmo soil had the highest clay content and lowest sand content of the 3 Malmo samples (54% clay vs 41 and 27%; 14% sand vs 23 and 28%). This cluster is only distinguishable in having the highest clay contents. Other samples had similar sand+silt and organic matter contents but remained in the main cluster. Another cluster in Figure 8 had moderate clay contents but high waterdrop counts. No apparent similarities could be discerned among the soils other than high waterdrop counts. The samples represent four soil series with moderate textures (SiCL, CL, C) not markedly different from other samples and a range in organic matter from 4 to 12%. The waterdrop index, WD1 is plotted against sand content in Figure 9 and again, shows some clusters. The high sand content (70 - 80%) cluster of 5 points was not present in the WD1 vs CLAY plot and the individuals appear to share only high sand and moderately low organic matter contents (3 - 5.4%). One other soil with a high sand content (73%) had a high WD1 (72) but had a slightly higher organic matter content (6.5%).

Multiple comparison of means was examined with a modification of the WD1 variable. The number of observations (aggregates exposed to waterdrops) for each sample was cut off at 35 in order for equal observations to occur on all samples (ie. the WD1 values for a few samples were based on 35 observations). The Duncans multiple range test was then applied to the 63 samples. The minimum distance allowed (alpha=0.05) was 11.43 and the maximum was 15.14. The standard deviation for WD1 presented above was

21. Clearly, there was a great amount of overlap and no groups could be discerned from the data. With the WD1 data for the Duncans test the soil series, classification subgroup, and erosion class were examined but no groupings or trends were observed.

In order to determine if the measurement of WD indices and their variability were related to any of the other variables measured, a correlation matrix was generated (Table 7, variables defined in Table 4). Overall, the WD indices are best correlated positively with organic matter, OM and negatively with sand content, SAND (correlations with wet sieving variables will be discussed in the wet sieving section). An alternative method of examining correlations is by a correlation profile (Figure 10). The LWD1 and LWD2 variables were similar in their correlations with the textural, organic, and K variables. Standard deviations of the waterdrop indices (SD1, SD2) had the highest correlation with SAND and LCLAY. This agrees with the observation that as sand content of the samples increased, the variability in the number of waterdrops required for aggregate breakdown was reduced. As well, when sand content increased, the number of waterdrops required for breakdown decreased (r=-0.278 for LWD1 and SAND). As clay content increased, waterdrop variability increased. Waterdrops required for breakdown tended to increase with clay although the relationship was not statistically strong (r=0.256 for LWD1 and LCLAY). During the tests it was noticed that some of the medium textured soils were quite variable in the manner in which they broke down. Some slumped as a whole while others fractured into relatively resistant sub-aggregates when about 1/3 of the total number of drops (required to force the aggregate(s) through the screen) had fallen. These aggregates may have attained a stabilized condition mediated by clay interaction with other factors such as organic matter, roots, etc. Although organic matter was not correlated with the variability of waterdrop indices, it was positively correlated with the waterdrop indices, WD1 and WD2.

In order to examine any change in relations between waterdrop variables over a change in textural and organic matter variables, grouping variables were created to split the data set into 4 clay classes, 4 sand classes, and 3 organic matter classes as follows:

Class no.	Clay content	no. in class	Sand content	no. in class	Organic matter	no. in class
1	0-11%	5	0-19%	7	0-4.0%	15
2	12-26%	36	20-39%	31	4.1-8.0%	28
3	27-40%	17	40-62%	19	8.1-12.5%	20
4	41-57%	5	63-81%	6		

When the CLAY-WD1 and CLAY-SD1 correlations were examined on a clay class basis it was observed that the correlations did not become statistically important ($p<0.05$) until the clay content of aggregates increased above 27% clay (Table 8a). Above 27% clay the number of waterdrops (WD1) increased with clay content until 40% and then decreased with increasing clay content. Over the same clay range (27-57%) the standard deviation (SD1) of the waterdrop index was first positively correlated with CLAY, then negatively correlated. One might expect that in the lower clay classes that SD1 or WD1 might be correlated with sand or silt content but such was not the case. In only one case (clay class 1) was WD1 correlated with the amount of very fine sand ($r=0.990$, $p=0.001$, $n=5$).

Overall there was a good positive correlation between OM and WD indices but not between OM and SD indices. Considered on a clay class basis (Table 8b), significant correlations were obtained only with high levels of clay. Since clay is known to be positively correlated with organic matter as well as interacting with other soil constituents to provide aggregate stability, it is expected that at intermediate levels of clay many forces/processes are at work and may not be easily separated. At high clay levels it appears that clay alone (Table 8a) and organic matter (Table 8b) are dominant in determining

waterdrop stability. Clay is more often correlated with variability in waterdrop stability than is organic matter. The overall clay-organic matter correlation was r=0.482 (p=0.000).

By organic matter classes,clay and organic matter were well correlated only at low organic matter levels (OM class 1) as was sand and organic matter (Table 8c). The WD1 index did show a correlation with OM below 4% organic matter where OM also was positively correlated with CLAY and negatively correlated with SAND. No correlations existed at intermediate levels of organic matter. Above 8% organic matter, WD1 was again correlated with OM. The WD1-OM correlations by organic matter class support the shape of the K versus OM plot (Figure 5) in that the plot has a distinct slope at organic matter levels below 4% and above 8 or 9% organic matter. The region between 4 and 9% organic matter is relatively flat and contains a large amount of scatter. The SD index was not correlated with organic matter at any organic matter class. Above 4% organic matter there were no correlations between organic matter and clay, or sand.

Inspection of relationships with WD indices on a sand class basis revealed no correlations between WD1 and SAND in any class (whereas the correlation between WD1 and CLAY increased with increasing clay content). There were no strong correlations between SD1 and any of the variables within different sand classes. SAND was not strongly correlated with OM within any sand class; however, CLAY and OM were correlated at medium and high levels of sand (Table 8d).

In summary, over the entire data set, WD indices had a higher correlation with organic matter than the textural variables. LWD1 was best correlated with LOM (r=0.368, p=0.003) and SAND (r=-0.278, p=0.027). In most cases the LWD2 variable produced no better correlations than LWD1. When the data are divided into 3 classes based on organic matter, WD indices were correlated with the high and low organic matter groups. Correlations between WD and OM did not exist when comparisons were made on a sand

class or clay class basis except for clay class 4 (high clay content). Correlations between LWD1-SAND did not exist when comparisons were done on a sand class basis. On a clay class basis, the LWD1-SAND correlations became significant as clay exceeded 26%. The correlation changed from positive in clay class 3 to negative in clay class 4. Overall the variability of the waterdrop test is correlated best with SAND (negatively) and LCLAY (positively). No trends were observed in LSD1-SAND on a sand class basis but the LSD1-CLAY correlation was strong in clay classes 3 and 4. Additionally it was observed that where clay content is high or sand content is moderate to high, there is a correlation between LCLAY and LOM. Sand content and organic matter are not correlated except for a negative correlation when organic matter levels are low. The LWD1 variable had a correlation with K overall of r=-0.222, p=0.080, but the relationship was not improved by inspection on a class basis (of the classes generated).

4.3 Wet Sieving

The wet sieving procedure yields a set of numbers for each sample. These are the masses of the soil (minus the sand) retained on each of the 6 stacked sieves. The numbers are usually developed to represent accumulative percentages starting with the smallest sieve and plotted against the corresponding sieve size. An example of the resulting graph appears in Figure 11 for samples 11 and 19. There can be a visual interpretation of the graph but in order to facilitate large numbers of samples, statistical testing, and unbiased comparisons, a single number index is desirable. The main index employed for these data is the mean weight diameter (MWD) which is the summation of the products of the mean diameter (x_i) of each size fraction and the proportion of the sample weight (w_i) occurring in that size fraction often expressed as (Kemper and Chepil, 1965):

$$MWD = \sum_{i=1}^{n} x_i w_i$$

This is a simpler method of calculating MWD than that used by Youker and McGuiness (1956) and correlates well (r=0.99) with the graphical/integral form developed by van Bavel (1949). The agreement of the summation to the graphical interpretation is best when a 4.76 mm sieve is used as the largest sieve instead of a 2.0 mm sieve (Kemper and Chepil, 1965). It is somewhat sensitive and biased to the larger aggregate sizes (Kemper and Chepil, 1965; Baldock and Kay, 1987). Kemper and Chepil (1965) also reported that the aggregate size distribution in most soils is closer to log-normal than normal and that geometric mean diameter (GMD) may be an alternative index of aggregation approximated by:

$$GMD = \exp\left[\frac{\sum_{i=1}^{n} w_i \log x_i}{\sum_{i=1}^{n} w_i}\right]$$

where x_i is the mean of the weight class and w_i is the mass of aggregates in that class. GMD is therfore the mean of the aggregate size distribution under a log transformation. Kemper and Chepil (1965) claimed the disadvantage in the GMD is the extensive work required to obtain the index and Baldock and Kay (1987) stated the GMD is biased towards the smaller aggregate sizes. Baldock and Kay (1987) described a less biased index of the wet sieving data with a power function of the relation between the cumulative percentage by weight (cpw) of the the aggregates less than a given diameter, and aggregate diameter (d). The power function was ;

$$cpw = A(d)^B$$

the coefficient and exponent were derived by log-transforming the data and regressing ln cpw on ln d using the method of least squares (Baldock and Kay,1987). The percentage difference in B over all treatments was found to be greater than that for A, thus, B was

used as the index for wet sieving data. In order to apply the method of Baldock and Kay (1987) in the current study, the wet sieving data (cumulative percentage) for screen sizes 0.250 mm through 8.00 mm were used with the SYSTAT nonlinear module, NONLIN, using the above model for cpw. The values obtained for B were then regressed (least squares method) against the MWD values calculated with the same sieve data. The two values were highly correlated (R=0.86, Figure 12). No advantage could be seen in using the B values so they were not used for further comparisons. If MWD is biased toward the larger aggregates, it should compare better with the waterdrop test and likely be a better index for erosion processes as it is the breakdown of the larger aggregates that initiates surface sealing predisposing the soil to runoff. The data in the aggregate distribution curve allow various parameters to be developed for statistical use. Recognizing the importance of larger aggregates, indices were calculated representing the percentage of water stable aggregates larger than 0.5 mm in diameter (MM5), larger than 2 mm in diameter (MM2), and between 0.5 and 2 mm in diameter (MM52). Bryan (1974) and Luk (1976) working with Alberta soils found that water stable aggregates >0.5 mm were the best single predictor of soil loss by rainfall simulation.

Initial inspection of the wet sieving variables was with scatter plots of the raw data using MWD as the standard or independent variable (Figures 13, 14, 15). MM2 gave the most linear relationship with MWD but had some dispersion at the lower end (Figure 13). The departure from linearity increased and amount of scatter increased when MM5 was plotted against MWD (Figure 14). MWD was found not to give as great a range of values as MM5 as indicated by the slope of Figure 14. The greatest dispersion was found with the MM52 versus MWD plot (Figure 15). The four wet sieving variables were all intercorrelated as indicated in Table 6 (MWD and MM2 were transformed for normality prior to linear correlation). LMWD had the highest correlation with LMM2 and second

highest with MM5. The single wet sieving variable that was correlated best with the remaining three was MM5.

MM52 was the wet sieving variable best correlated with the texture variables with MM5 often being second best. Both MM52 and MM5 were positively correlated with clay ($p<0.05$). All wet sieving variables were negatively correlated with sand although the correlation was not significant ($p<0.05$) between any pairs. Organic matter was positively correlated with wet sieving variables although, again, not at a significant level with any of them. The K and K4 variables were significantly correlated with MM52 and K with MM5 (because of mutual correlations with texture).

Over the whole data set the best correlations for three of the four wet sieving variables (other than their intercorrelations) were found with the waterdrop indices. A correlation profile between the waterdrop and wet sieving variables is presented in Figure 16. The wet sieving variables representing the larger aggregate fraction were the most strongly correlated with the waterdrop indices. LMM2 gave the best and, LMWD the second best, positive correlations with LWD1&2. MM52 was not correlated with waterdrop indices.

Overall, wet sieving variables and waterdrop variables had similar correlations with texture and organic matter variables. No improvement in, or development of, correlation patterns was found when wet sieving variables and texture variables were compared on a class basis. The smaller wet sieving variables (MM5, MM52) were better correlated with K and K4 than the larger wet sieving variable (LMM2), LMWD or the LWD indices.

4.4 Separation by soil group indices

The two waterdrop, two K, and four wet sieving variables were examined on a group basis. The data sets were grouped on a series (20), erosion class (6), and texture class (8) basis. The dependent variables (e.g. WD1, K, MM2, etc.) were examined using ANOVA

and least square means over all groups and by contrasts between groups. The grouping variables for series, erosion, and textural classes are displayed in Table 3. Overall, the variables did not separate the soils well by the grouping variables used. Thus, results are presented in a non-graphical form. One example of the class contrasts for K and K4 on an erosion class basis is presented for reference in Table 9. The format of Table 9 is a slight modification of the SAS output.

On an erosion class basis, K4 provided the best separation followed by K. This was not surprising considering the erosion classes were generated with a restricted (with respect to organic matter) calculation of K. Of the 15 possible 2-way contrasts between classes over the whole data set (e.g. 1x2, 1x3, ... 3x4), K4 was significantly different ($p<0.05$) between 13 of them, and K between 10 of the 15 (see Table 9). Although the percentage difference in the value of K or K4 between classes was nearly the same, there was greater variance of K values within a class due to the unrestricted organic matter calculation. Thus, fewer significant contrasts on a K basis would be expected. None of the other variables was significantly different over all erosion classes. The best separation of 2 class contrasts by the remaining variables was with MM52 which displayed significant differences between 3 of the 15 possible contrasts.

Results on a series class basis were not much different from those on an erosion class basis. The 2 K variables provided the greatest number of significantly different contrasts while the WD and wet sieving variables showed significantly different class contrasts in rare instances only. For the K variables, all series were significantly different from others from 4 to 18 times of the 19 possible 2-way contrasts per series class (e.g. 1x2, 1x3,... 1x20). On average approximately half of the contrasts were significant for both K and K4. The 3 series showing the most number of significant contrasts were 3, 20, and 17 which had 18, 18 and 17 significantly different contrasts respectively. The series 3, 20 and 17 are the Drumheller, Caroline, and Glory series, all quite extreme series from the standpoint of

texture. The WD variables showed no separation of soils on a series basis except for series 12 (Keephills) which displayed significant differences for half of the possible contrasts. Series 12 had the highest WD value. The wet sieving indices showed no separation of soils with the exception of MM52 which displayed significant differences for 14 of the 19 possible contrasts with series 3 (Drumheller).

Eight separate textural classes were present in the data sets. Again, K and K4 showed the best separation of textural classes with significant differences occurring for approximately half of the 28 possible 2-way class contrasts. The silty-loam class was consistently significantly different when contrasted with all other textural classes for both K and K4. K4 showed significant differences between 6 of the 7 possible contrasts between the clay class and other classes. K showed significant differences 3 times between the clay class and others. With respect to the WD indices, the only significant differences found were those between the silty-clay-loam textural class and all other classes. The wet sieving variables showed only rare occurrences of significant differences between textural classes. The only consistent trend was with MM52 which displayed significant differences between the clay class and all others textural classes.

4.5 Prediction of K

Recognizing that the equation for K as put forward by Wischmeier and Smith (1978) presents an exponential relationship between soil texture and K value, the suitability of linear regression was examined. The 3 variables used to calculate K: % silt+very fine sand, % clay, and % organic matter were regressed against K (calculated by nomograph formula with no restriction on % organic matter). The complete data set was used because it was not intended to include any of the wet sieving variables in the multiple regression selection. K was coded (1000*K) to reduce the number of zeros in the coefficients.

Inspection of the residuals indicated extra terms (squares or cross products) were needed in the model. It was found that the following equation had normally distributed residuals:

$$1000K = -34.357+4.178VFS-5.139LCLAY+7.315LOM-0.584(LOM*SVFS)$$

$$R^2=0.987$$

All variables, the constant and multiple coefficient of determination were significant ($p<0.05$). Adding the other 2 variable interaction terms (LCLAY*SVFS and LOM*LCLAY) increased R to 1.00 (R^2 to 0.999). The same variables regressed against the K value calculated with a maximum of 4% organic matter (K4) resulted in a similar highly significant equation that adequately predicted K4 (R=0.985).

Stepwise regression was done with K on the above variables plus all remaining variables for texture, wet sieving and waterdrop parameters (alpha to enter = 0.05, to remove = 0.10). The data set used was the shortened set (56 cases) in order for stepwise regression to consider only the correct wet sieving variable data. The method yielded OM, SVFS, and SAND as variables to describe K. In order to obtain normally distributed residuals, an interaction factor of SVFS*OM was needed. No loss in the accuracy of the equation occurred if the single OM variable was dropped. Thus, equation 1.1 in Table 10 explained 99% of the variance in the unrestricted calculated K value. Deletion of the SAND variable still allowed a useful predictive equation for K using only 2 variables (equation 1.2, Table 10) although the standard error of the estimate was double that of equation 1.1. Stepwise regression done with K4 (K calculated with OM restriction of 4%) on all variables resulted in the same ones being selected as for K. Initially five terms were selected (SVFS, SILT, LCLAY, OM, SVFS*OM) but it was found that a good two variable equation could be developed with little loss in the R^2 value or standard error (equation 1.3, Table 10).

The organic matter data was bimodal in distribution. The probability plot of the OM data indicated a shift in the distribution at 4.5% OM (Figure 17). A log transformation was imposed to normalize the data in the complete data set. The result was a more linearized relationship with the dependent variables. In view of the distinct original distribution and the maximum limit of 4% OM on the K nomograph, the short data set was split in two at 4.5% OM. The resulting two data sub-sets were examined for normality and no transformations were indicated for OM. Stepwise regression was done on the 0-4.5% OM data (23 cases) and SVFS, OM, LCLAY and SAND were chosen as variables for an equation predicting K with a R^2 of 0.99. The best 2 variables found to provide an adequate equation for predicting K within the 0-4.5% organic matter range were SVFS and LCLAY with a R^2 of 0.98 (equation 1.4, Table 10). For K4, LCLAY was not selected by the stepwise procedure and the best 2 variable predictive equation for K4 in the 0-4.5% OM range contained SVFS and LCLAY with an R2 of 0.98 (equation 1.5, Table 10). Stepwise regression of K with the 4.5+% organic matter data set (33 cases) selected the variables SVFS, SAND, and OM for a R^2 of 0.95. The best 2 variable equation for prediction of K in the 4.5-13% organic matter range used OM and SVFS and had an R^2 of 0.89 (equation 1.6, Table 10). Stepwise regression with K4 as the dependent variable yielded LCLAY, SVFS and LWD1 as predictors with an overall R^2 of 0.99. The best 2 variable equation for prediction of K4 contained SVFS and LCLAY with a R^2 of 0.99 (equation 1.7, Table 10).

4.6 Predicting waterdrop indices

Using the smaller data set (56 samples) to avoid incorrect wet sieving indices, stepwise regression was used to find the most suitable predictor variables for LWD1 (alpha to enter = 0.05 and remove = 0.10). Two texture variables, SAND and LCLAY, and two wet sieving variables, MM52 and LMM2 were selected for LWD1 (R^2=0.62). The best predictive equation for LWD1 contained LCLAY, LMM2 and MM52 with a R^2 of 0.60

(equation 2.1, Table 10). The best 2 variable equation for LWD1 contained LCLAY and LMM2 but the R^2 dropped to 0.46. Stepwise regression with LWD2 selected LCLAY, LMM2 and MM52 as predictors with a R^2 of 0.55 (equation 2.2, Table 10). The best 2 variable equation for LWD2 contained LMM2 and MM52 but the R^2 dropped to 0.46.

In addition to the low R^2 values, another weakness of the WD equations was the large standard error of the estimates, which were 13 and 11 for equations 2.1 and 2.2 respectively (for non-transformed values of WD). Prediction of a WD1 value +/- 13 would be of little value (recall for WD2 the mean was 46, sd was 18). Thus, predictive equations for WD indices could not be generated with the variables available in the data set.

The best correlation obtained was between LWD1 and LMM2 where r=0.627, p=0.000. LMWD gave the second best correlation with WD1 where r=0.514, p=0.000. This indicates waterdrop indices are related to wet sieving data although wet sieving does not explain the majority of the waterdrop index. The best correlation between LWD1 and a texture variable was with SAND (r=-0.307, p= 0.022) and the second best was with SILT (r=0.264, p=0.049). The corrected or dampened waterdrop index LWD2 was not as closely correlated as LWD1 to either the wet sieving or texture variables.

4.7 Predicting wet sieving variables

With wet sieving variables poorly correlated with other variables measured, it would not be expected that predictive equations could be derived. Stepwise regression (alpha to enter=0.05 and remove = 0.10) was tried on the four wet sieving variables against all other variables (except other wet sieving variables to avoid collinearity).

The best predictive equation derived (R^2=0.45, p=0.000) was for LMM2 containing LWD1 and LCLAY as predictors (equation 3.1, Table 10). LWD1 and PH were selected

for prediction of MM5 (equation 3.2, Table 10) while only LWD1 was selected for predicting LMWD (equation 3.3, Table 10). LCLAY and PH were selected for predicting MM52 (equation 3.4, Table 10).

Poor correlations between wet sieving variables and other variables measured did not allow for reliable predictive equations for wet sieving variables. Regression coefficients are not significant and standard errors of the estimates are large.

4.8 Discussion

The wet sieving method employed was a time consuming analysis. Starting with clean equipment, 3 samples could be sieved over a period of 2 days (3 replicates each). Part of the length of time could be attributed to a small apparatus (3 cannister/sieve assemblies) though the collection, drying, and sand corrections of the sample on each sieve took the majority of the time. In addition to time, a lot of laboratory space was needed for the analysis. Room is required for the apparatus as well as substantial oven space and bench space for handing of samples. Due to all of these lesser constraints, multiple-sieve wet sieving is destined to a more minor role in the future than it has played in the past. Recently, in response to the time required by the six-sieve method initiated by Yoder (1936), the University of Guelph has pursued a faster method of aggregate stability measurement involving a single-sieve wet sieving in combination with clay dispersion (Kay, 1988).

The texture variables (sand, silt, clay) displayed no discernable trends or relations with any of the wet sieving variables. The results of the waterdrop tests showed no discernable patterns with sand or silt. Waterdrop test versus clay content vaguely followed trends reported in earlier research.

Waterdrop stability versus clay content displayed a wide scatter but it is noted that WD increases with clay content with maximum levels in the 15 to 35% clay range (Figure 18). Chepil (1954, 1955) found aggregation increased to a maximum at the 20% clay level and decreased to a minimum at 80% clay (and decreased below 20% clay). He found a parabolic relationship between aggregation and clay content similar to the one superimposed on Figure 18 but with much less scatter of points (aggregation was measured by dry sieving). Kemper and Koch (1966) found water stable aggregation continually increased with clay content (10-90%) in a gentle curvilinear (convex) trend. They used a vacuum saturation pretreatment of aggregates prior to wet sieving which would dampen the variability of the data. Bruce-Okine and Lal (1975) found waterdrop counts increased with clay content of aggregates and decreased with sand content. However, they only tested 5 samples (3 A horizons, 2 B horizons) so reliable equations could not be developed. Wustamidin and Douglas (1985) from Indonesia and Australia respectively found very significant negative correlations between aggregates and waterdrop energy to breakdown (vegetation differences, if any, on the soils sampled were not stated). They found no correlation between clay and waterdrop energy but also noted that one soil (of the 17 tested) with which they were unable to predict the waterdrop index using measured variables was a vertisol with montmorillonite clay. The other soils contained dominantly illite and kaolinite clays. With low activity clays the other size fractions would dominate or play a more important role in aggregation. The large amount of variability in Figure 18 is likely due to the interaction effects between the textural fractions, organic matter, and the inter-aggregate variability exposed by the WD test. In the current study, if the 4 high clay cases are removed from the data set, it can be visualized the resulting form of the minima is a gentle increase in WD with an associated increase in clay content. This trend is displayed by the shifted linear regression line of LWD1 on LCLAY as indicated in Figure 19. The line represents the threshold value of LWD1 for a given clay content. The scatter above the minimum threshold is due to other factors (organic matter and other unmeasured factors).

Wet sieving variables and organic matter showed no relationships in the data presented. The waterdrop index WD1 increased with organic matter but, once again, substantial scatter was present. The correlation between LWD1 and LOM using the full data set was 0.368, p=0.003. Assuming at any level of organic matter there can be a range of WD values due to inter-aggregate variability and an interaction of factors not measured, there is still an increase in the minimum of the WD - OM relationship. This is demonstrated in Figure 20 where the fitted linear regression line has been shifted down to the minima. This slope appears to be similar to that observed by Kemper and Koch (1966) for soils above 2% organic matter. They found aggregate stability decreased rapidly below 2% organic matter. The lowest organic matter level encountered in this study was 2.8%. Wustamidin and Douglas (1985) found a correlation of 0.625** (17 soils) between organic matter and waterdrop energy. Bergsma and Valenzuela (1981) worked with 10 Spanish soils and found no correlation between organic carbon or "organic matter including roots" and waterdrop energy. Dumas (1965) working in Tunisia found a correlation of 0.62*** (n=30) between organic matter and aggregation. Bryan (1974) working with Alberta soils found a significant correlation (about -0.3*) between organic matter and splash, wash, and total soil loss determined with a laboratory rainfall simulator. Luk (1979) working with Alberta soils found very significant correlations between organic carbon and soil loss (by rainulator) by different slope classes but not when compared by management class (cultivated, grassland, forest). Bryan (1974) correlated three wet sieving variables with soil loss and found MM5 the best, MM2 the second best and %>3mm the worst though still significant. All three were negatively correlated (as was OM) with soil loss. Bryan (1974) also reported an insignificant correlation between organic matter and aggregate stability which was not consistent with an earlier study of his with British soils where organic matter and aggregate stability had a correlation of r=0.52. The soils used by Bryan (1974) and his earlier study were non-cultivated soils. Luk (1979) found a curvilinear relation between MM5 and organic carbon (regression significant at 10% level) with a

maximum at 8% OC and declining at an equal rate on both sides. The maximum organic carbon level measured in the current study was 7.5%. Within the cultivated subgroup Luk (1979) reported a correlation of 0.57 (n=20) between MM5 and organic carbon but indicated a lack of significance. The significance of r table in Steel and Torrie (1980) indicates the significance would occur at the 99% level. In the current study no significant correlation existed between organic matter and any of the wet sieving variables including MM5 (see Table 6); however, MM5 and LWD1 were correlated at the 99% level. The influence of organic matter on rainulator tests of virgin soils appears consistent but its influence on aggregate stability appears contradictory. The importance of organic matter appears to become more prominent as one progresses from analysis of processes (rainulator soil loss) and water stable aggregation (MM5), to an energy-based water stability test (WD).

The USLE - K factor was not highly correlated with the waterdrop indices. Nor was it correlated with the largest wet sieving fraction, MM2. The correlation increases as the wet sieving fraction is representative of a smaller aggregate diameter. The best correlation of the wet sieving and waterdrop indices was between MM52 and the K factor. K can be adequately predicted with a combination of the textural and organic variables used to calculate K by the nomograph method. Only three other references have been found where K has been calculated or correlated with variables other than those used for the original derivation of the nomograph K. The earliest one, not acknowledged in the English literature, was from research conducted in, at the time, French Tunisia by Dumas (1965) who found a good correlation between the % aggregation (by the Hénin method of sieving in water without pretreatment, benzene pretreatment, or alcohol pretreatment) and the K factor. The K factor was determined by field rainfall simulation (this was before availability of the nomograph derivation of K). A correlation of 0.83 (n=30) was obtained between logK and % aggregation. Dumas (1965) derived predictive graphs and equations

for K on the basis of aggregation, organic matter and moisture content. De Meester and Jungerius (1978) and Bergsma and Valenzuela (1981) both worked on soils of south-central Spain and found no correlation between K and waterdrop disintegration of aggregates. However, both pairs of authors cited an unpublished thesis that found a high correlation (r=0.86) between K and the number of waterdrops for aggregate shatter for some Spanish soils. De Meester and Jungerius (1978) did find a correlation (r=0.61*) between the percentage of particles <100μm after breakdown and K. That finding coincides with the findings of this study of an increasing correlation between K and aggregate size as the aggregate size index represents a smaller size fraction. Therefore, K (and thus soil loss by USLE), is better correlated with the amount of fine material after a waterdrop test or wet sieving rather than the waterdrop index or amount of large water stable aggregates. This implies that K is not closely related to the the initial stage of erosion (aggregate breakdown) but rather the secondary stages of the process (the amount and stability of small secondary aggregates).

There are several approaches that are popular in the assessment of soil erosion. The largest scale is the watershed approach in which the watershed can be hundreds of square kilometers down to the 1000 ha range. This is the large scale used by engineers in flood control and dam sedimentation projections. Sometimes watersheds are studied at a scale smaller than 1000 ha by geomorphologists and geographers. Once the field size has been reduced from 100 ha to a few ha, it is sometimes referred to as an open plot study and measurements can be made at points on the site with collection troughs. Roels and Jonker (1985) noted that soil loss sample measurements that deviate by 50-100% from the population soil loss are the rule rather than the exception and caution the use of soil loss data quoted in the literature. Rainfall simulation is a popular method to generate data in the field and laboratory. It is attractive in that many variables can be controlled but there are many apparatus designs and methodology differences. The use of rainfall simulation in the

laboratory may not be much, if any, of an improvement over wet sieving or the waterdrop method. The sample is disturbed in taking it from the field, often sieved and assembled in a tray in a particular manner. China et al. (1985) noted that if soil was reconstructed in the lab according to field conditions (with a slowly permeable layer) the sediment concentration of runoff increased by 25% due to entrapped air below the wetting front. Rainfall simulation in the field takes into consideration the effects of the complexities of soil structure and layering and by repeated applications at the same site data can be generated over a range of antecedent moisture conditions. Rainfall simulation also removes the uncertainty of rainfall occurring at a particular rate on a particular location, saving research resources. Rainfall simulation in the field does however, have great limitations in plot size necessitating replications to approach the accuracy of a large plot or population of soil loss estimates (Roels and Jonker, 1985).

Researchers and soil specialists will continue to use the USLE as it is convenient, relatively easy to use with available data, allows comparison with other USLE generated data, and appears to be accepted in North America. Unfortunately, the accuracy of the equation is not well documented. In order for the equation to be accurate for Canadian use it needs to be completely verified and/or corrected variable by variable and indeed, this may ultimately lead to the development of a different, more reliable, more encompassing equation. Until such time, researchers should note the assumptions and restrictions made in their application of the USLE. For example, in the current study only 15 of the 63 samples (24%) satisfied the restriction of no more than 4% organic matter and only 50 (80%) satisfied the textural restrictions (sand<65%, clay<35%) for the determination of K (Wischmeier and Mannering, 1969; Wischmeier et al., 1971). Considering both restrictions together, only 12 samples (19%) came from fields that could have the USLE applied to them. Considering the accuracy of the nomograph estimation of K as stated by

Wischmeier et al. 1971, the K value for 8 of the 12 samples should be within 6.4% of the true values, 11 of the 12 samples within 11% of the true values.

In order to develop a predictive erosion loss equation applicable to all agricultural soils in Canada, extensive field data are required. Ruling out the modelling approach due to the enormous amounts of data and measured parameters required, the alternatives are a field rainfall simulator approach or laboratory tests of parameters important in the erosion process. The field rainfall simulation approach does require a significant amount of manpower and financial resources, but is desirable as a tool for estimation of erodibility for the following reasons:

1) It encompasses the high energy initial component of the water erosion process, rainfall, which is important in the initial breakdown of aggregates.
2) It measures the entire erosion process (including runoff) thus it will be correlated with K which appears to be sensitive to secondary aggregate size and distribution.
3) The soils are measured *in situ* taking into account peculiarities of structure, layering, coarse fragments, etc.
4) With repeated measurements the soil can be tested under different moisture conditions.
5) It can be supplemented with laboratory measurements.
6) Rainfall simulation may be essential to testing models derived from laboratory or theoretical work.

In the laboratory, an energy-based index like the waterdrop method should be one of the tools used. The WD indices have shown better correlations with important parameters such as clay and organic matter than has the less energy intensive method of wet sieving. The test could be modified to consist of a group of aggregates such as 40 g of dry aggregates from 1 to 4 mm in size exposed to a high energy based test (vigorously wet sieved or exposed to rainfall). The end point of such a test does not need to be total disintegration

but rather the percent remaining after a given time interval. As observed in the current study with the waterdrop method, often aggregates can break down into stable sub-aggregates which may not pass a screen indicative of the end point of the test. Nevertheless, these aggregates may be small enough to be easily eroded in the field and thus, a critical point of erodibility would have been reached. Due to the acceptance of the MM5 variable by others (Bryan and Luk, 1981) and the fact that it was the wet sieving variable best correlated with other factors in this study, it should also be utilized as a laboratory analysis. Sieving with a 5 mm sieve alone would greatly simplify and speed up the wet sieving process.

5.0 SUMMARY AND CONCLUSIONS

The waterdrop method of assessing aggregate stability was quick and easy to administer. It is a high energy laboratory test which represents the initial stage of water erosion, that is aggregate breakdown due to waterdrop impact. It has been used with success around the world although the soils tested in most of the studies were representative of a wide range of management (vegetation) and/or soil types (e.g. temperate vs tropical soils). In the current study of a wide range of Alberta soils cultivated to annual crops, the waterdrop method displayed a wide variation of results preventing its use to differentiate soils on the basis of aggregate stability, soil series, texture, or erosion class. Thus, as a solitary method the waterdrop test cannot differentiate different soils under the same management (cultivation). The waterdrop test was not correlated with the K factor of the Universal Soil Loss Equation but was correlated with several of the wet sieving analysis variables.

Wet sieving analysis with a stack of 6 sieves proved to be a labourious method of assessing aggregate stability to water. The method is less energy intensive than the waterdrop method but does indicate the slaking resistance of aggregates and the size distribution of water stable aggregates. Three of the four wet sieving variables examined were statistically correlated ($p<0.01$) with the waterdrop indices. The waterdrop indices were best correlated with the % of aggregates greater than 2 mm in diameter (largest sieve used was 4 mm); the second best was mean weight diameter and the third, % of aggregates greater than 0.5 mm in diameter. The variable representing the smallest aggregate size, % of aggregates between 0.5 and 2 mm was not statistically correlated with a waterdrop index. Wet sieving indices were no better than waterdrop indices in separating the soils into groups on the basis of soil series, texture, or erosion class.

Since Canada has no long term erosion plot studies (other than 2 sites in Ontario) the nomograph estimation of K must be used if it is desired to apply the USLE in Canada.

Only 12 of the 63 Alberta soils sampled in the current study were within the allowable range of the soil limits of the nomograph. Regardless of whether the limits of the equation are adhered to or if the equation is extrapolated, a range of K values can be generated. These K values were not statistically correlated with any of the waterdrop indices or wet sieving indices with the exception of the small aggregate fraction, % of aggregates between 0.5 and 2 mm, and marginally correlated with the % of aggregates greater than 0.5 mm (p of approximately 0.05 depending on the choice of K variable used).

Multiple linear regression analysis allowed predictive equations to be developed for wet sieving variables and waterdrop variables. The best equation for wet sieving was for the % of aggregates greater than 2 mm which explained 45% of the variability using 3 independent variables. The best equation for a waterdrop index explained 60% of the variability in the waterdrop index using 3 independent variables.

Linear regression equations derived to predict K explained more than 90% of the variation in K using 2 or 3 variables. The combination of textural and organic matter variables always included the "silt+very fine sand" variable. The regression equations for the prediction of K in the current study are constrained or biased by the fact they were derived using the variables of the nomograph estimation of K as developed in the U.S.A. The variables and their relationships as determined by the nomograph are, of course, the most likely to be selected for regression analysis of K. Considering the large number of soils in the current study that existed beyond the range of the nomograph, it is possible that a different selection or wieghting of variables might occur if the studies for the generation of the K nomograph were reproduced in Canada. Verification of K values and of the variables used to derive the values is required before the USLE can be considered applicable to Canadian soils.

To summarize the conclusions in point form they are:

a) The waterdrop method was quick and easy to use but could not differentiate a wide variety of cultivated soils on the basis of erosion, texture, or soil series classes.

b) The waterdrop method was not correlated with the USLE soil erodibility factor K and thus, is unsuitable to use as a predictor of K.

c) The wet sieving method of measuring aggregate stability was laborious and did no better than the waterdrop method in separating the soils on the basis of soil series, texture, or erosion class.

d) Aggregate stability to waterdrops is negatively correlated with sand content, positively correlated with clay content and very strongly positively correlated with organic matter.

e) The waterdrop test was correlated the best with the wet sieving variable that represented the largest fraction of the sample (% greater than 2 mm). The K factor was correlated the best with the wet sieving variable that represented the smallest size fraction (% between 0.5 and 2 mm). The waterdrop index was significantly related to the texture and organic matter variables but the wet sieving variables were not.

f) Without validating the assumptions of the USLE and the K factor, regression equations can be derived to predict K for Albertan soils. Regression equations using the measured parameters produced poor predictive equations for waterdrop and wet sieving variables.

TABLES

Table 1. Summary of characteristics in the Yoder wet sieving method.

	Sample size (g)	Stroke (cm)	Cycles per min	Duration (min)	Sieves size (mm)	Pretreatment
Yoder (1936)	50	3.18	30	30	5, 2, 1, 0.5, 0.25, 0.1,	air dry
van Bavel (1953)	25	3.81	30	10	5, 2, 1, 0.21	tap water, sand correction airdry, vacuum wetting - optional
Toogood & Lynch (1959)	60	4.0	30	30	4, 2, 1, 0.5, 0.25, 0.12	passing 4 mm, field moisture
Gupta (1965)	25	3.81	30	30	0.7, 0.4, 0.2, 0.15, 0.1, 0.08	passing 0.85 mm, air dry
Kemper & Chepil (1965)	25	3.81	30	10	5, 2, 1, 0.21	passing 8 mm, air dry or prewet (+/- vacuum)
Williams et al (1966)	-	2.54	30	-	1, 0.5, 0.25	air dry, prewetted
Bryan (1968)	25	2.54	30	30	3, 2, 1, 0.5	passing 6 mm, air dry

Table 2. Summary of characteristics in evolution of the waterdrop method.

	Aggregate size	Drop size	Height of fall (m)	KE/drop* ($x10^{-4}$J)	Drop rate	End point	Replicates	Pretreatment
McCalla (1944)	0.15 g	4.7 mm (0.05 g)	0.3	1.56	1/4.5s	passing 1mm screen	20	air dry
Smith & Cernuda (1951)	1.0 g 6-13 mm	0.1 g	0.6	5.45	1/s	passing 6 mm screen	5-10	
Low (1954)	4-5 mm	0.1 g	1.0	8.53		passing 3 mm screen	20	prewetted (-5cm)
Bruce-Okine & Lal (1975)	0.74 to 3.75 g	6.7 mm 0.157 g	1.0	14.51		passing 2 mm screen	5	prewetted pF=0 to 7
Imeson & Jungerius(1976); DeMeester & Jungerius (1978)	4-5 mm	0.1 g	1.0	8.53		passing 3mm screen	30	filter paper on sand (-5cm)
Bergsma & Valenzuela(1981)	4-5 mm	0.09 g 5.5 mm	1.0	7.64	1.33/s	passing 3mm screen	20	filter paper on sand (-5cm)
Bryan & Luk (1981)	5.7-6.7 g & 1-2mm	3 mm	0.3	0.44	1/s	passing 5.7 mm and 1 mm sieve		
Lindsay & Gumbs (1982)	3-3.5 g 2-2.5 cm	0.073 g	1.0	6.14			20	air dry
Wustamidin et al. (1983); Wustamidin & Douglas (1985)	0.1, 0.15, 0.2 g	2.4, 3.9, 5.2 mm	1.0	0.58, 2.56, 6.22	1/s	passing 1 mm fibre glass gauze	25	air dry (65% RH)
Farres & Cousen (1985)	4-6 mm	2.9 mm 0.013 g	2 m	1.91	1.83/s	>90% passing 3 mm hole		25% moisture by weight

* Kinetic energies calculated using drop velocities from Epema and Riezebos (1983).

Table 3. Listing of samples alphabetically by soil series within increasing erosion classes.

Sample No.	Soil Series	Series Codes	Classification[1]	Texture Class & Code	Parent Material	Erosion Class[2]
37	Redwater	RDW 1	O. DG	SL 6	GlacFluv	1
39	Redwater	RDW 1		SL 6		1
43	Redwater	RDW 1		SCL 5		1
20	Antler	ATL 2	O. BL	SCL 5	Morainal	2
21	Antler	ATL 2		SCL 5		2
28	Antler	ATL 2		CL 2		2
12	Drumheller	DMH 3	O. DB	C 1	GlacLac	2
13	Drumheller	DMH 3		C 1		2
14	Drumheller	DMH 3		C 1		2
32	Malmo	MMO 4	E. BL	C 1	GlacLac	2
33	Malmo	MMO 4		C 1		2
46	Malmo	MMO 4		CL 2		2
18	Peace Hills	PHS 5	O. BL	SL 6	GlacFlu	2
27	Peace Hills	PHS 5		SCL 5		2
29	Peace Hills	PHS 5		SL 6		2
34	Camrose	CMO 6	BL. SS	L 3	Morainal	3
35	Camrose	CMO 6		CL 2		3
64	Camrose	CMO 6		L 3		3
19	Falun	FLU 7	O. DG	CL 2	Morainal	3
36	Falun	FLU 7		SCL 5		3
40	Falun	FLU 7		SCL 5		3
15	Halkirk	HKR 8	DB. SS	L 3	Morainal	3
16	Halkirk	HKR 8		SL 6		3
17	Halkirk	HKR 8		SL 6		3
22	Ponoka	POK 9	E. BL	L 3	FluvLac	3
30	Ponoka	POK 9		L 3		3
31	Ponoka	POK 9		SiL 8		3
23	Rimbey	RMY 10	O. DG	CL 2	GlacLac	3
24	Rimbey	RMY 10		CL 2		3
25	Rimbey	RMY 10		L 3		3
47	Culp	CUL 11	O. GL	LS 4	GlacFlu	4
48	Culp	CUL 11		SL 6		4
49	Culp	CUL 11		SL 6		4
2	Keephills	KHS 12	D. GL	CL 2	GlacLac	4
57	Keephills	KHS 12		SiCL 7		4
58	Keephills	KHS 12		SiL 8		4
60	Keephills	KHS 12		SiCL 7		4
52	Macola	MLA 13	D. GL	SiL 8	GlacLac	4
54	Macola	MLA 13		CL 2		4
56	Macola	MLA 13		CL 2		4
38	Uncas	UCS 14	D. GL	SCL 5	Morainal	4
41	Uncas	UCS 14		SCL 5		4
42	Uncas	UCS 14		CL 2		4
5	Breton	BTN 15	O. GL	L 3	Morainal	5
6	Breton	BTN 15		L 3		5
7	Breton	BTN 15		L 3		5
61	Cooking Lake	COA 16	O. GL	L 3	Morainal	5
62	Cooking Lake	COA 16		L 3		5
63	Cooking Lake	COA 16		L 3		5

cont...

Table 3 cont.

Sample No.	Soil Series	Series Codes	Classification(1)	Texture Class & Code	Parent Material	Erosion Class(2)
44	Glory	GOY 17	O. GL	SiL 8	GlacFlu	5
45	Glory	GOY 17		L 3		5
50	Glory	GOY 17		SiL 8		5
1	Highvale	HGV 18	O. GL	SiL 8	GlacLac	5
3	Highvale	HGV 18		SiCL 7		5
4	Highvale	HGV 18		CL 2		5
59	Highvale	HGV 18		SiL 8		5
51	Maywood	MYW 19	O. GL	SiL 8	GlacLac	5
53	Maywood	MYW 19		CL 2		5
55	Maywood	MYW 19		SiL 8		5
8	Caroline	CAR 20	BR. GL	SiL 8	GlacFlu	6
9	Caroline	CAR 20		SiL 8		6
10	Caroline	CAR 20		SiL 8		6
11	Caroline	CAR 20		SiL 8		6
26	*discarded*					

1) Corresponding classification and parent material taken from Soil Names File, Ag. Canada, Soil Survey, Edmonton.
2) Erosion Classes for series as reported in Tajek et al., 1985.

Table 4. Variable name descriptions.

Variable code	Description
SAND	Percent sand in sample
SILT	Percent silt in sample
CLAY	Percent clay in sample
LCLAY	ln(CLAY)
SVFS	Percent silt+very fine sand
OM	Percent organic matter
LOM	ln(OM*100)
K	USLE-K factor with no organic matter restriction (calculated by nomograph formula and converted to SI units)
K4	USLE-K factor calculated with maximum 4 % OM (calculated by nomograph formula and converted to SI units)
WD1	Average waterdrop count on 40 aggregates
LWD1	ln(WD1)
WD2	Average waterdrop count on 30 aggregates (removing outliers from WD1)
LWD2	ln(WD2)
SD1	Standard deviation of WD1
LSD1	ln(SD1)
SD2	Standard deviation of WD2
LSD2	ln(SD2)
MM2	Percent by weight of aggregates >2.0 mm
LMM2	ln(MM2)
MM5	Percent by weight of aggregates >0.5 mm
LMM5	ln(MM5)
MM52	Percent by weight of aggregates 0.5-2.0 mm
LMM52	ln(MM52)
MWD	Mean weight diameter of aggregates (mm)
LMWD	ln(MWD*10)

Table 5. Pearson simple correlation coefficients for parameters used in calculating K.

	K	K4	LOM	SVFS	LCLAY	SAND	SILT
K	1.000						
K4	0.817	1.000					
LOM	-0.849	-0.441	1.000				
SVFS	0.692	0.916	-0.288	1.000			
LCLAY	-0.579	-0.606	0.482	-0.263	1.000		
SAND	-0.036	-0.110	-0.106	-0.473	-0.669	1.000	
SILT	0.484	0.657	-0.163	0.871	0.075	-0.769	1.000

(n=63; r=0.2446 for p=0.05; r=0.3179 for p=0.01; r=0.3994 for p=0.001)

Table 6. Pearson simple correlation matrix for short data set.

	LMWD	MM5	LMM2	MM52	LWD1	LWD2	LSD1	SAND	SILT	LCLAY	SVFS	OM	K
LMWD	1.000												
MM5	0.746	1.000											
LMM2	0.770	0.764	1.000										
MM52	0.488	0.883	0.423	1.000									
LWD1	0.514	0.408	0.627	0.108	1.000								
LWD2	0.501	0.346	0.621	0.024	0.974	1.000							
LSD1	0.393	0.408	0.438	0.253	0.793	0.668	1.000						
SAND	-0.041	-0.162	-0.013	-0.231	-0.307	-0.242	-0.326	1.000					
SILT	0.030	-0.073	0.125	-0.146	0.264	0.262	0.108	-0.715	1.000				
LCLAY	0.021	0.266	-0.122	0.414	0.188	0.124	0.292	-0.596	-0.100	1.000			
SVFS	-0.028	-0.174	0.109	-0.291	0.168	0.193	0.009	-0.382	0.860	-0.448	1.000		
OM	0.094	0.217	0.094	0.186	0.170	0.207	-0.090	0.010	-0.268	0.410	-0.350	1.000	
K	-0.078	-0.272	0.029	-0.343	-0.066	-0.060	-0.004	-0.030	0.548	-0.672	0.765	-0.811	1.000
K4	-0.056	-0.248	0.107	-0.380	0.032	0.075	-0.109	-0.056	0.670	-0.719	0.934	-0.434	0.859
	LMWD	MM5	LMM2	MM52	LWD1	LWD2	LSD1	SAND	SILT	LCLAY	SVFS	OM	K

Number of observations: 56; r=0.2593 for p=0.05; r=0.3365 for p=0.01

Table 7. Simple correlation coefficients for the waterdrop variables.

	LWD1	LWD2	LSD1	LSD2
LWD1	1.000			
LWD2	0.979	1.000		
LSD1	0.812	0.708	1.000	
LSD2	0.918	0.865	0.913	1.000
SAND	-0.278	-0.231	-0.260	-0.181
SILT	0.211	0.213	0.063	0.088
LCLAY	0.256	0.204	0.295	0.191
SVFS	0.136	0.158	-0.008	0.044
LOM	0.368	0.387	0.099	0.170
LMWD	0.569	0.553	0.467	0.539
LMM2	0.652	0.644	0.504	0.641
LMM5	0.473	0.428	0.462	0.487
LMM52	0.271	0.209	0.340	0.307
K	-0.222	-0.211	-0.130	-0.122
K4	-0.019	0.020	-0.137	-0.060

(n=63; r=0.2446 at p=0.05; r=0.3179 at p=0.01)

Table 8a. Correlations of waterdrop and waterdrop index variability with clay content on a clay class basis.

Clay class	Clay content	LWD1-LCLAY		LSD1-LCLAY	
		r	p	r	p
1	0-12 %	0.747	0.147	0.861	0.061
2	12-27 %	-0.034	0.846	-0.198	0.247
3	27-40%	0.544	0.024	0.618	0.008
4	40+%	-0.893	0.041	-0.798	0.105

Table 8b. Correlations of waterdrop and waterdrop index variability with organic matter on a clay class basis.

Clay class	Clay content	LWD1-LOM		LSD1-LOM	
		r	p	r	p
1	0-12 %	0.169	0.785	-0.061	0.922
2	12-27 %	0.286	0.091	-0.053	0.761
3	27-40%	-0.057	0.829	-0.203	0.434
4	40+%	0.914	0.030	0.870	0.055

Table 8c. Correlations between organic matter, waterdrop index, sand, and clay on an organic matter class basis.

OM class	Organic matter content	LCLAY-LOM		SAND-LOM		LWD1-LOM	
		r	p	r	p	r	p
1	0 - 4 %	0.603	0.017	-0.779	0.001	0.510	0.052
2	4 - 8 %	0.159	0.418	0.114	0.562	0.149	0.449
3	8 - 12 %	0.095	0.689	-0.157	0.509	0.496	0.026

Table 8d. Correlations between clay and organic matter on a sand class basis.

Sand class	Sand content	LCLAY-LOM	
		r	p
1	0 - 19%	0.220	0.636
2	20-39%	0.509	0.003
3	40-62%	0.587	0.008
4	63-81%	0.906	0.013

Table 9. SAS output of least square means, t-test for K4 and K contrasted by erosion class.

By Erosion Class (ECLS)

General Linear Models Procedure
Least Squares Means

Erosion Class	K4 LSMean	i/j	Pr > |T| Ho: LSMean(i)=LSMean(j) 1	2	3	4	5	6
1	0.0166	1	.	0.8306*	0.0207*	0.0305	0.0001	0.0001
2	0.0175	2		.	0.0008	0.0022	0.0001	0.0001
3	0.0270	3			.	0.8273	0.0017	0.0001
4	0.0265	4				.	0.0013	0.0001
5	0.0353	5					.	0.0012
6	0.0482	6						.

(* example: When compared on the basis of K4 values, soils of erosion class 1 were not significantly different from 2 but were significantly different from class 3 at the p=0.0207 level of confidence.)

Erosion Class	K LSMean	i/j	Pr > |T| Ho: LSMean(i)=LSMean(j) 1	2	3	4	5	6
1	0.0130	1	.	0.3393	0.9085	0.3312	0.0004	0.0001
2	0.0076	2		.	0.1618	0.0028	0.0001	0.0001
3	0.0124	3			.	0.0696	0.0001	0.0001
4	0.0185	4				.	0.0001	0.0001
5	0.0339	5					.	0.0044
6	0.0484	6						.

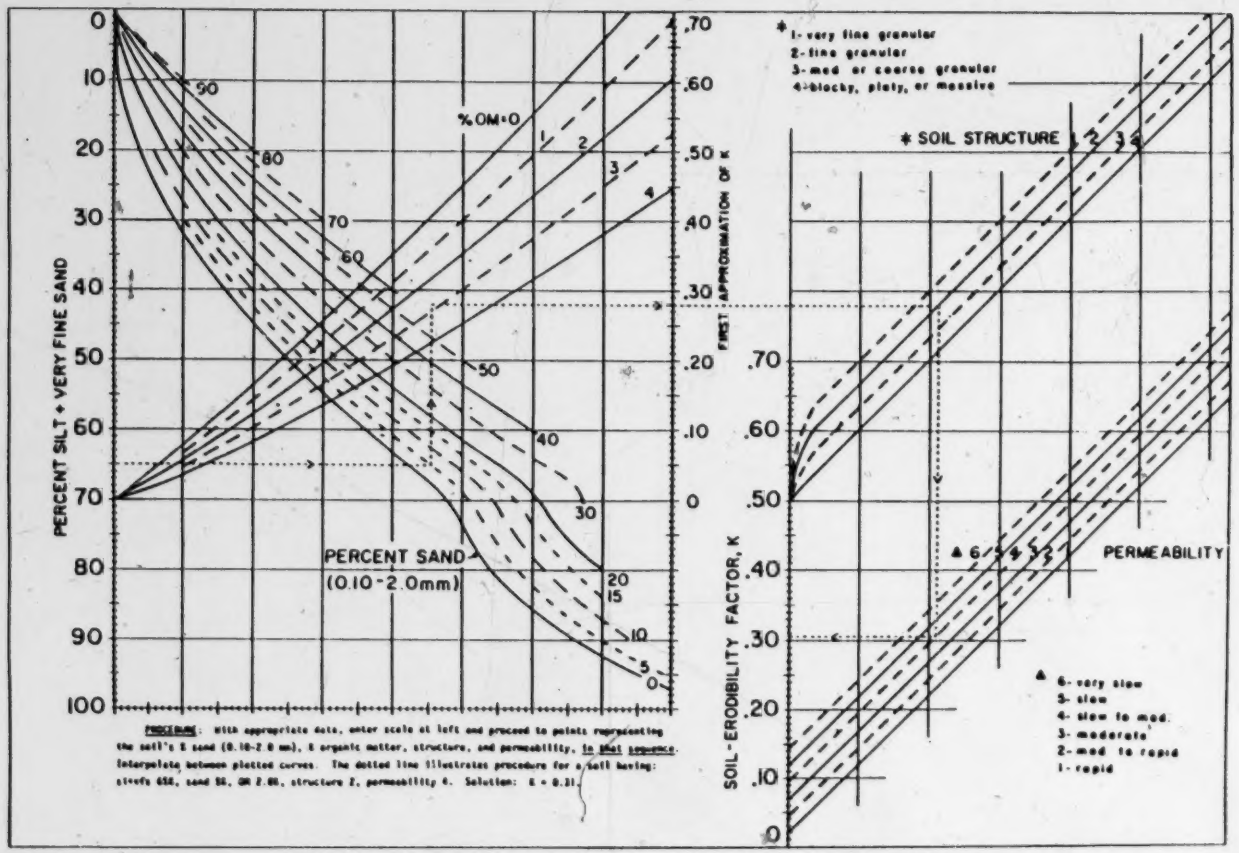
Table 10. Regression equations done with data set of 56 cases. (*=p≤0.05; **=p≤0.01; ***=p≤0.001; complete equation data available in Appendix B)

Eqn. No.	Dependent Variable	Regression Constant	Partial Regression Coefficients OM	SVFS	SAND	LCLAY	SVFS*OM	R^2
1.1	1000K	-28.308***	1.484***	1.257***	0.176***		-0.099***	0.992***
1.2	1000K	-8.354***		1.026***			-0.075***	0.958***
1.3	1000K4	25.476***		0.660***		-9.951***		0.985***
1.4	1000K	22.929***		0.733***		-10.642***		0.977***
1.5	1000K4	22.684***		0.726***		-10.316***		0.980***
1.6	1000K	15.762***	-2.773***	0.385***				0.892***
1.7	1000K4	24.774***		0.608***		-9.002***		0.991***

			SAND	LCLAY	MM5	LMM2	MM52	R^2
2.1	LWD1	1.790***		0.394***		0.469***	-0.014***	0.597***
2.2	LWD2	49.041***	-0.347***		-0.500***	1.978***		0.548***

			LWD1	LCLAY	PH			R^2
3.1	LMM2	-1.281	1.271***	-0.377*				0.453***
3.2	MM5	111.726***	21.464***		10.689**			0.278***
3.3	LMWD	-0.533	0.656***					0.265***
3.4	MM52	-40.548*		9.068**	5.759*			0.246***

FIGURES



-The soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is $100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)$ where M = (percent si + vfs) (100 − percent c), a = percent organic matter, b = structure code, and c = profile permeability class.

Figure 1. Soil erodibility factor (K) nomograph. (adapted from Wischmeier and Smith, 1978)

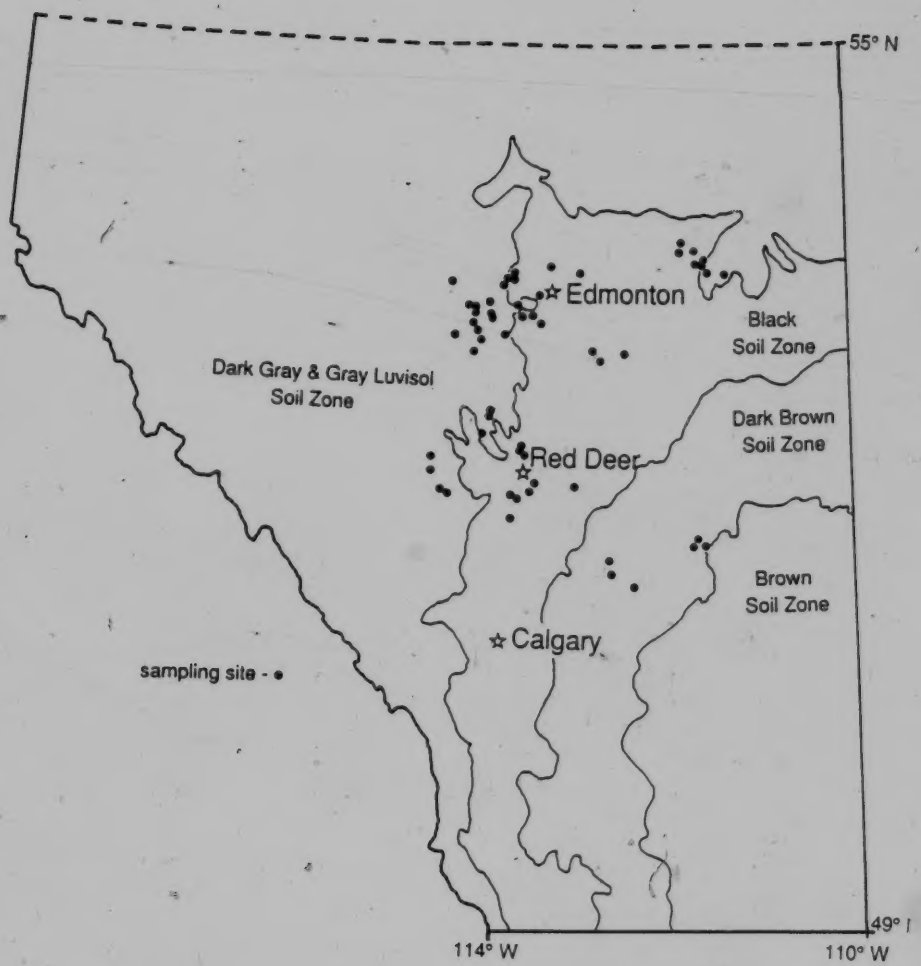


Figure 2. Sampling sites within central Alberta.

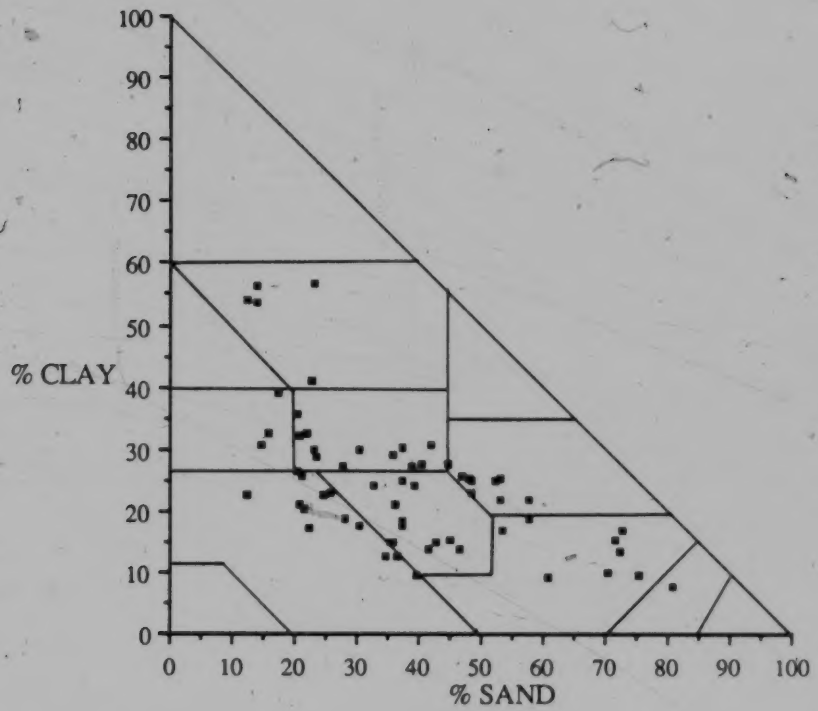


Figure 3. Texture distribution of samples.

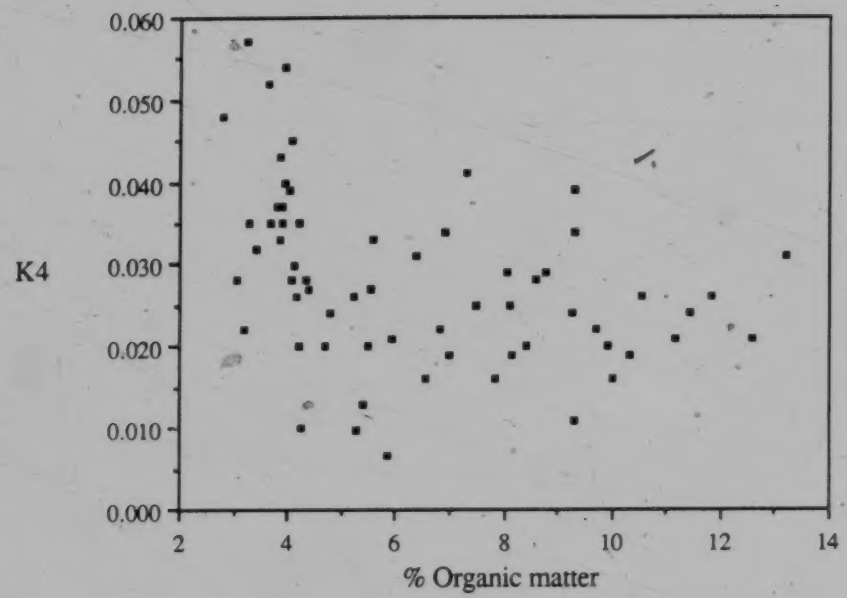


Figure 4. K calculated with a maximum of 4 % organic matter plotted against actual organic matter contents.

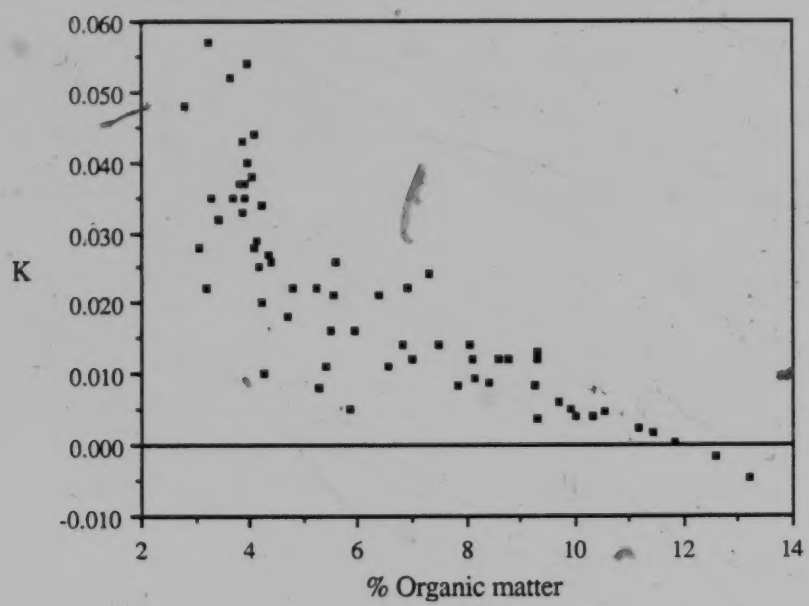


Figure 5. K calculated with no restriction on % organic matter plotted against actual organic matter.

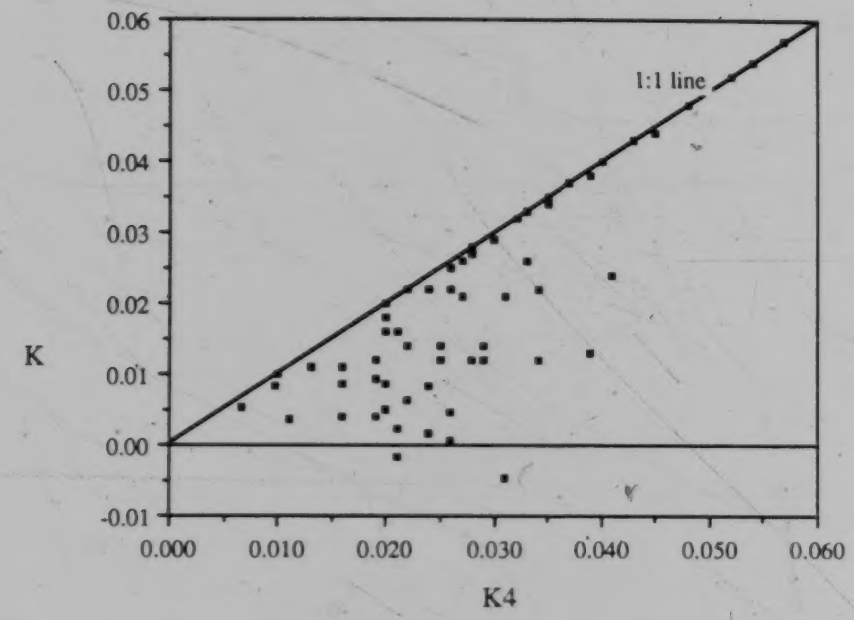


Figure 6. Calculated K values with and without a 4 % organic matter restriction.

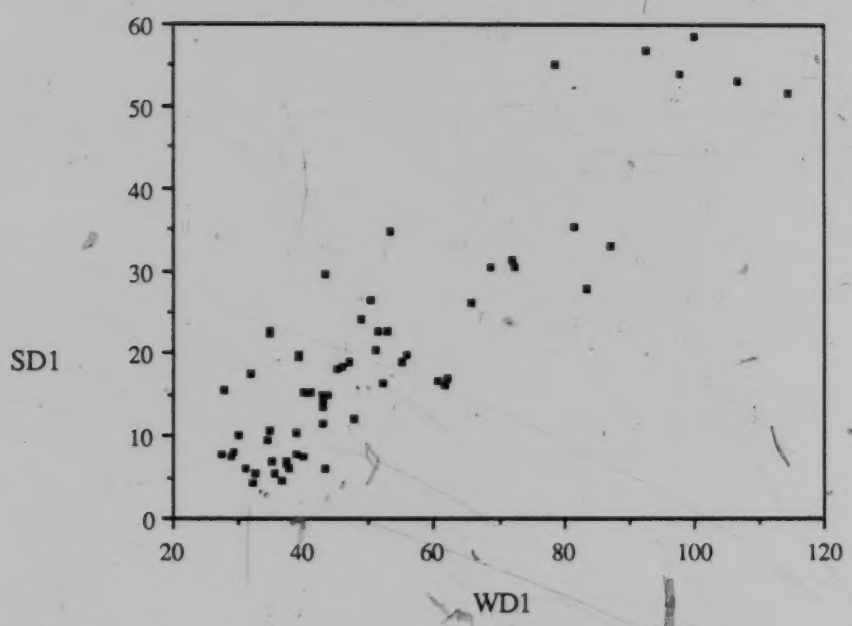


Figure 7. Standard deviation of waterdrop index versus waterdrop index.

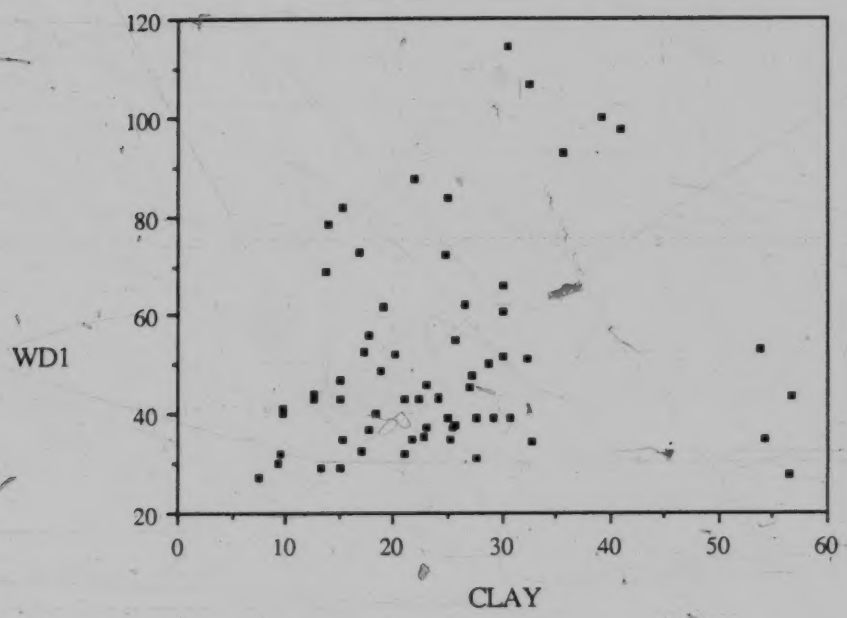


Figure 8. Waterdrop index plotted against clay content.

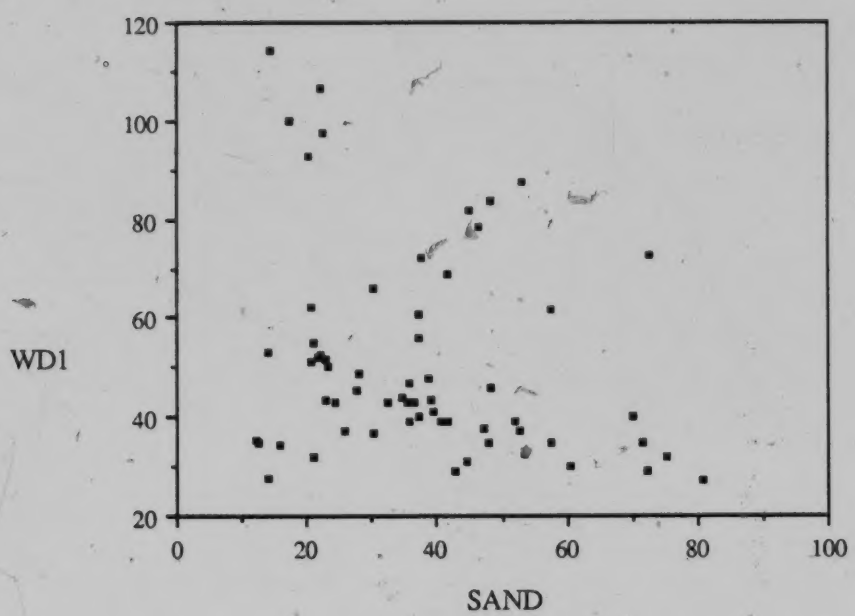


Figure 9. Waterdrop index plotted against sand content.

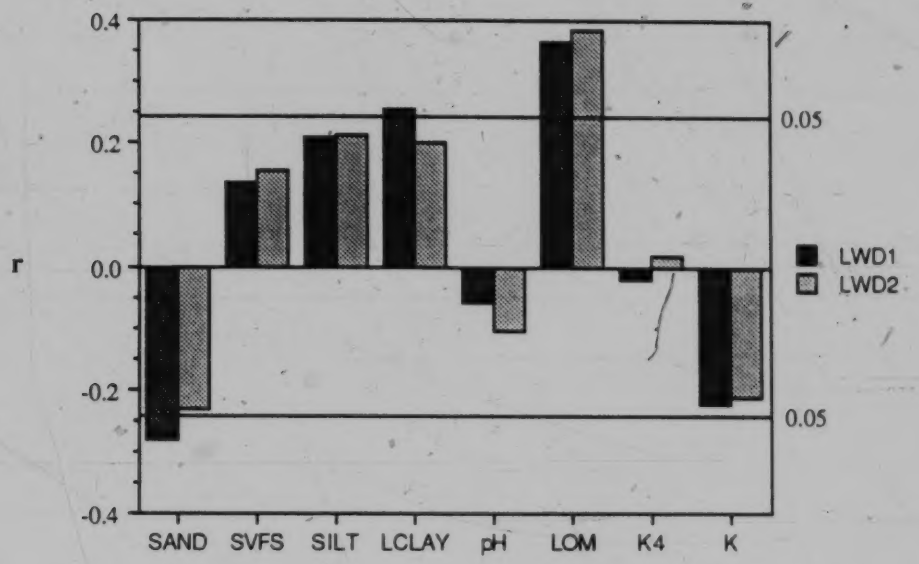


Figure 10. Correlation profile of simple correlation coefficients, r, for textural, organic, pH and K variables versus waterdrop variables.

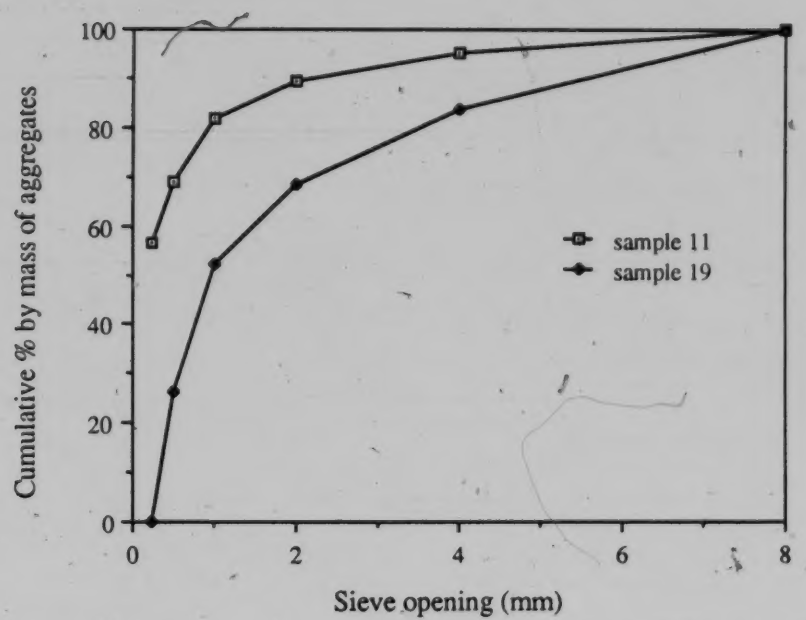


Figure 11. Aggregate size distribution curve for two soil samples.

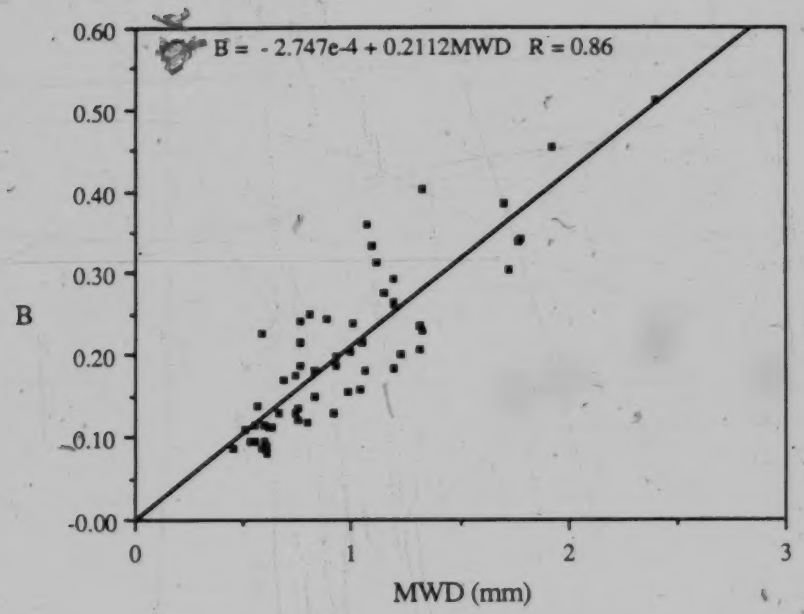


Figure 12. B exponent index versus mean weight diameter.

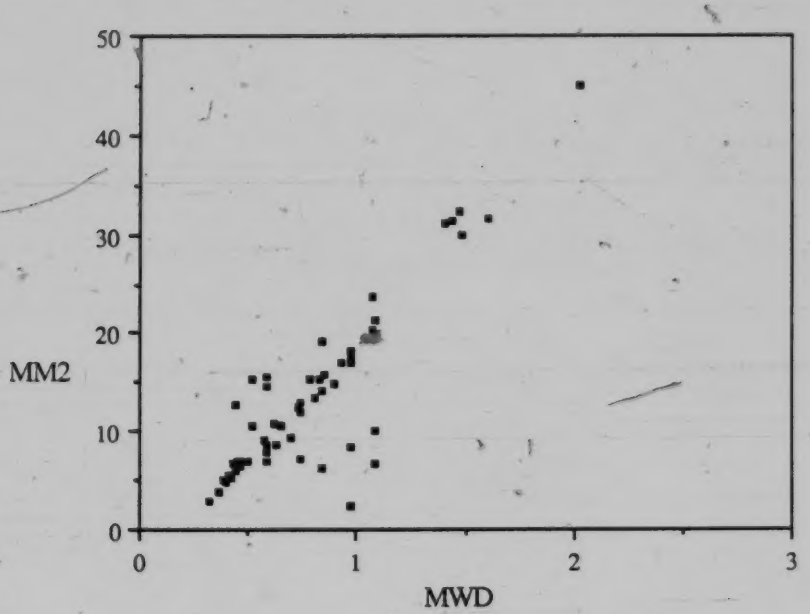


Figure 13. The relationship of MM2 and MWD.

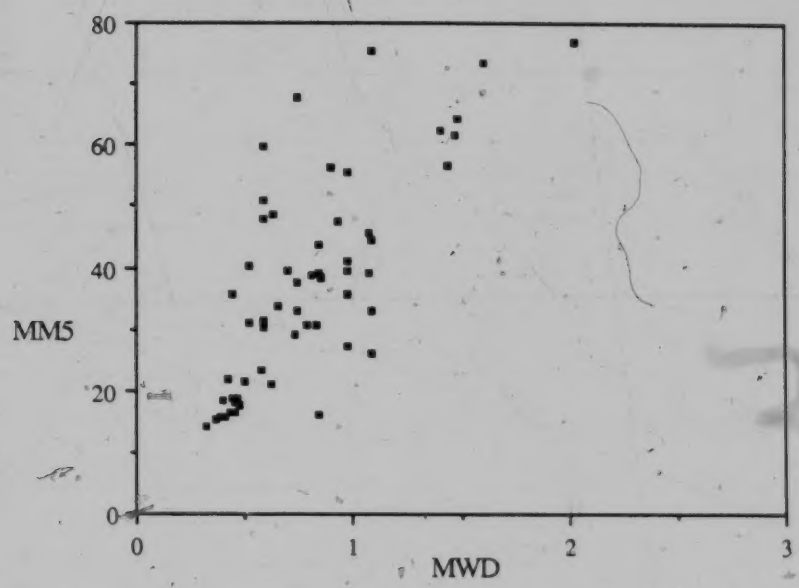


Figure 14. The relationship between MM5 and MWD.

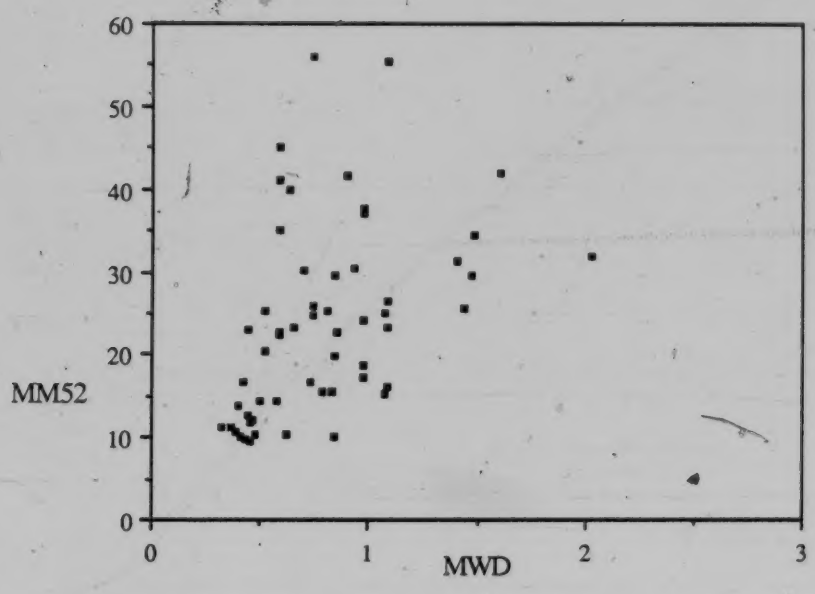


Figure 15. The relationship between MM52 and MWD.

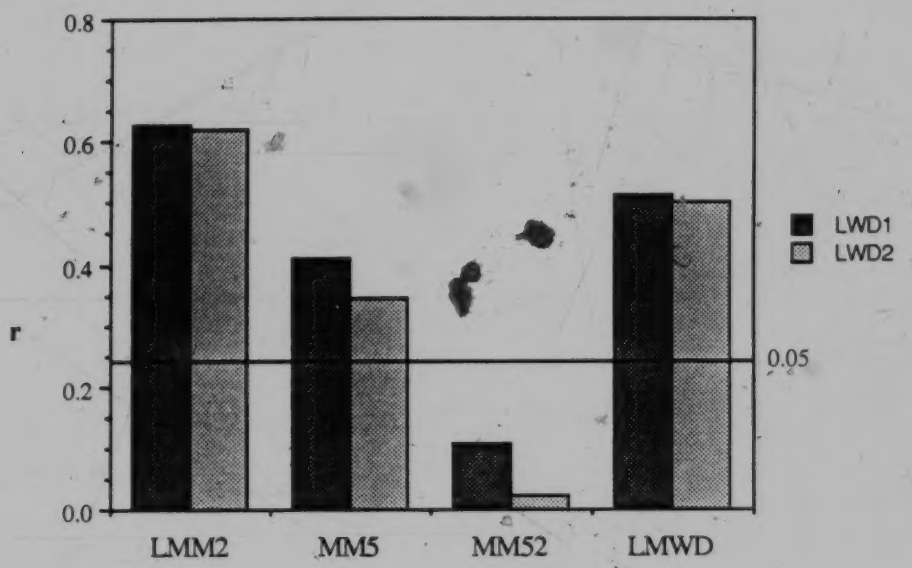


Figure 16. Correlation profile of WD and wet sieving variables.

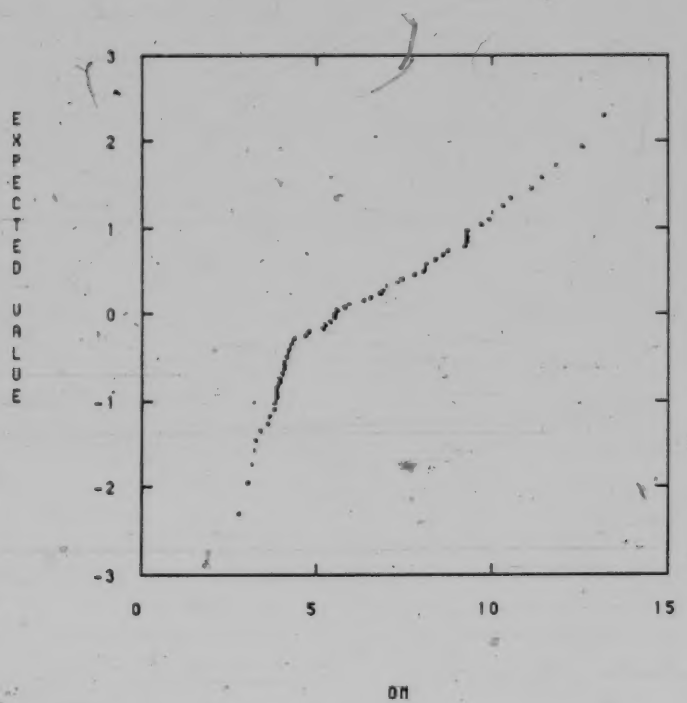


Figure 17. Probability plot of OM for 63 cases.

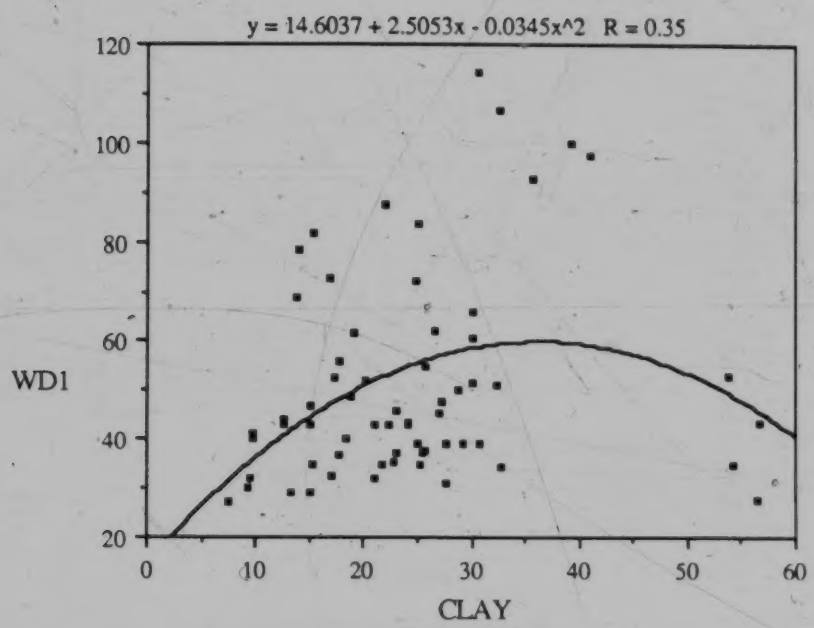


Figure 18. Relationship between WD1 and CLAY.

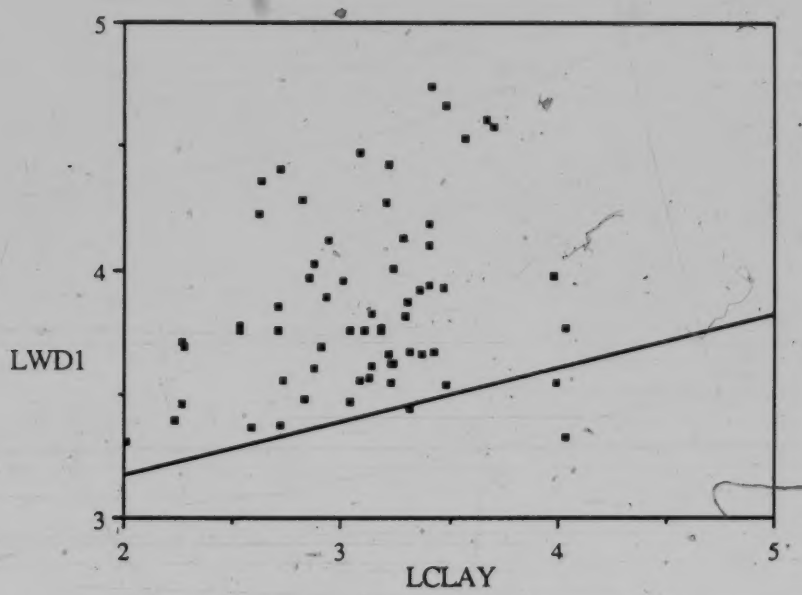


Figure 19. The simple linear regression line of LWD1 on LCLAY shifted down to the minima of the plot.

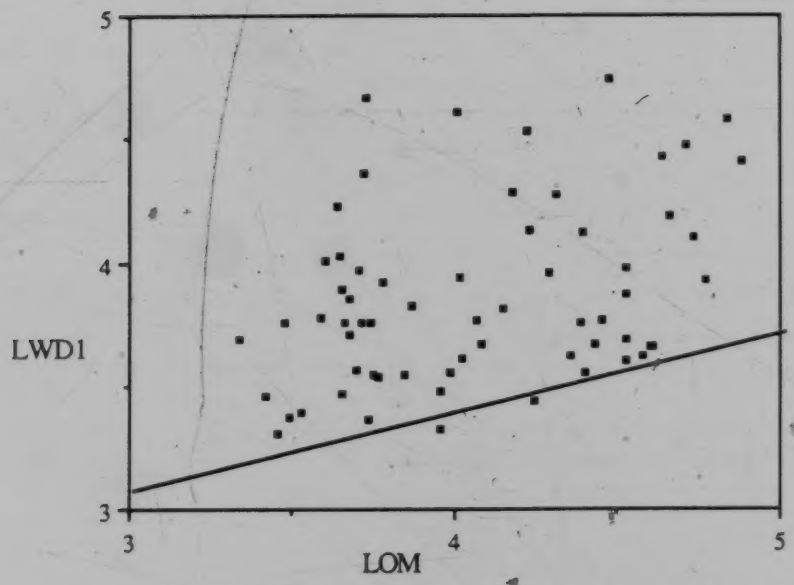


Figure 20. The simple linear regression line of LWD1 on LOM shifted down to the minima of the plot.

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APPENDIX A.

PROGRAM MWD

This program will calculate the mean weight diameter of wet sieving data. It is an adaptation of one created by Colin Wytowich of the Dept. of Soil Science. Input is the oven dry weight (g) of soil minus sand loaded on the sieves followed by the oven dry weight of soil on each sieve from the smallest to largest. The input data file is called ' MWDAT.FOR ' and ends with a zero. The output file will be labelled ' RES'.

```
      REAL WT(7),TWT,PCT(7), A, AREA, AREA2, SIZE(8)
      OPEN (UNIT=5, FILE='MWDAT.FOR', STATUS='OLD')
      OPEN (UNIT=13, FILE='RES', STATUS='NEW')

10    TWT=0
      DO 15 I=1,7
         WT(I)=0
         PCT(I)=0
         SIZE(I)=0
15    CONTINUE
      AREA=0
      A=0
      AREA2=0

      READ(5,*) TWT

      IF (TWT .GT. 0) THEN

         READ(5,*) (WT(I),I=2,7)

         WT(1)=TWT-WT(2)-WT(3)-WT(4)-WT(5)-WT(6)-WT(7)

         AREA=0
         SIZE(1)=0
         SIZE(2)=.124
         SIZE(3)=.246
         SIZE(4)=.495
         SIZE(5)=.991
         SIZE(6)=1.981
         SIZE(7)=3.962
         SIZE(8)=8.0

         DO 50 I=1,7
            PCT(I)=(WT(I)/TWT)*100
            A=PCT(I)*((SIZE(I+1)+SIZE(I))/2)
            AREA=AREA+A
50       CONTINUE

         AREA2=AREA/100

         WRITE(13,1) AREA2
1        FORMAT(4X,'MWD=', F8.3)

      GOTO 10
      END IF
      CONTINUE
      STOP
      END
```

APPENDIX B.

SYSTAT output for equations in Table 10.

Equation 1.1

```
DEP VAR:    1000K        N:    56     MULTIPLE R:   .996     SQUARED MULTIPLE R:   .992
ADJUSTED SQUARED MULTIPLE R:   .991        STANDARD ERROR OF ESTIMATE:            1.377

   VARIABLE     COEFFICIENT     STD ERROR      STD COEF TOLERANCE      T     P(2 TAIL)
CONSTANT            -28.308         2.462         0.000 1.0000000  -11.500      0.000
      OM              1.484         0.386         0.249  .0392506    3.847      0.000
    SUFS              1.257         0.043         1.111  .1115363   28.989      0.000
    SUFS*
      OM             -0.099         0.007        -0.829  .0419257  -13.260      0.000
    SAND              0.176         0.013         0.187  .8092917   13.140      0.000

                                ANALYSIS OF VARIANCE
   SOURCE    SUM-OF-SQUARES     DF   MEAN-SQUARE       F-RATIO         P
 REGRESSION       11463.922      4       2865.980     1511.990       0.000
   RESIDUAL          96.671     51          1.896
```

Equation 1.2

```
DEP VAR:    1000K        N:    56     MULTIPLE R:   .979     SQUARED MULTIPLE R:   .958
ADJUSTED SQUARED MULTIPLE R:   .956        STANDARD ERROR OF ESTIMATE:            3.036

   VARIABLE     COEFFICIENT     STD ERROR      STD COEF TOLERANCE      T     P(2 TAIL)
CONSTANT            -8.354         1.833         0.000 1.0000000   -4.557      0.000
    SUFS              1.026         0.033         0.907  .9483621   31.284      0.000
    SUFS*
      OM             -0.075         0.003        -0.627  .9483621  -21.629      0.000

                                ANALYSIS OF VARIANCE
   SOURCE    SUM-OF-SQUARES     DF   MEAN-SQUARE       F-RATIO         P
 REGRESSION       11071.990      2       5535.995      600.505       0.000
   RESIDUAL         488.602     53          9.219
```

Equation 1.3

```
DEP VAR:   1000K1        N:    56     MULTIPLE R:   .992     SQUARED MULTIPLE R:   .985
ADJUSTED SQUARED MULTIPLE R:   .984        STANDARD ERROR OF ESTIMATE:            1.377

   VARIABLE     COEFFICIENT     STD ERROR      STD COEF TOLERANCE      T     P(2 TAIL)
CONSTANT            25.476         2.084         0.000 1.0000000   12.224      0.000
    SUFS             0.660         0.016         0.766  .7989739   40.747      0.000
   LCLAY            -9.951         0.498        -0.375  .7989739  -19.962      0.000

                                ANALYSIS OF VARIANCE
   SOURCE    SUM-OF-SQUARES     DF   MEAN-SQUARE       F-RATIO         P
 REGRESSION        6614.461      2       3307.231     1744.863       0.000
   RESIDUAL         100.457     53          1.895
```

cont...

Appendix B. cont.

Equation 1.4

DEP VAR: 1000K N: 23 MULTIPLE R: .988 SQUARED MULTIPLE R: .977
ADJUSTED SQUARED MULTIPLE R: .974 STANDARD ERROR OF ESTIMATE: 1.776

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	22.929	3.785	0.000	1.0000000	6.057	0.000
SUFS	0.733	0.034	0.776	.9066550	21.597	0.000
LCLAY	-10.642	0.910	-0.420	.9066550	-11.689	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	2633.988	2	1316.994	417.631	0.000
RESIDUAL	63.070	20	3.153		

Equation 1.5

DEP VAR: 1000K4 N: 23 MULTIPLE R: .990 SQUARED MULTIPLE R: .980
ADJUSTED SQUARED MULTIPLE R: .978 STANDARD ERROR OF ESTIMATE: 1.603

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	22.684	3.418	0.000	1.0000000	6.637	0.000
LCLAY	-10.316	0.822	-0.414	.9066550	-12.550	0.000
SUFS	0.726	0.031	0.782	.9066550	23.689	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	2552.670	2	1276.335	496.528	0.000
RESIDUAL	51.410	20	2.571		

Equation 1.6

DEP VAR: 1000K N: 33 MULTIPLE R: .944 SQUARED MULTIPLE R: .892
ADJUSTED SQUARED MULTIPLE R: .884 STANDARD ERROR OF ESTIMATE: 2.334

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	15.762	2.286	0.000	1.0000000	6.894	0.000
SUFS	0.385	0.038	0.616	.9849976	10.183	0.000
DM	-2.773	0.211	-0.795	.9849976	-13.129	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1345.537	2	672.768	123.500	0.000
RESIDUAL	163.426	30	5.448		

---

cont...

Appendix B. cont.

Equation 1.7

DEP VAR: 1000K4 N: 33 MULTIPLE R: .996 SQUARED MULTIPLE R: .991
ADJUSTED SQUARED MULTIPLE R: .991 STANDARD ERROR OF ESTIMATE: 0.758

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	24.771	1.717	0.000	1.0000000	14.431	0.000
LCLAY	-9.002	0.445	-0.355	.9362740	-20.232	0.000
SUFS	0.608	0.013	0.845	.9362740	48.175	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1977.717	2	988.859	1720.808	0.000
RESIDUAL	17.239	30	0.575		

Equation 2.1

DEP VAR: LWD1 N: 63 MULTIPLE R: .812 SQUARED MULTIPLE R: .660
ADJUSTED SQUARED MULTIPLE R: .642 STANDARD ERROR OF ESTIMATE: 0.217

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	1.651	0.251	0.000	1.0000000	6.585	0.000
LCLAY	0.412	0.069	0.503	.8182386	5.994	0.000
LMM2	0.496	0.051	1.005	.5417316	9.744	0.000
MM52	-0.012	0.003	-0.464	.5216305	-4.410	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	5.365	3	1.788	38.127	0.000
RESIDUAL	2.767	59	0.047		

Equation 2.2

DEP VAR: LWD2 N: 63 MULTIPLE R: .743 SQUARED MULTIPLE R: .552
ADJUSTED SQUARED MULTIPLE R: .529 STANDARD ERROR OF ESTIMATE: 0.238

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	3.058	0.139	0.000	1.0000000	21.956	0.000
SAND	-0.007	0.002	-0.329	.9769035	-3.731	0.000
MM5	-0.004	0.002	-0.298	.3156016	-1.922	0.059
LMM2	0.444	0.073	0.939	.3148503	6.049	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4.133	3	1.378	24.232	0.000
RESIDUAL	3.354	59	0.057		

---

cont...

Appendix B cont.

Equation 3.1

DEP VAR: LMM2 N: 56 MULTIPLE R: .673 SQUARED MULTIPLE R: .453
ADJUSTED SQUARED MULTIPLE R: .432 STANDARD ERROR OF ESTIMATE: 0.476

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-1.281	0.817	0.000	1.0000000	-1.569	0.123
LWD1	1.271	0.195	0.674	.9645800	6.509	0.000
LCLAY	-0.377	0.157	-0.249	.9645800	-2.405	0.020

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	9.924	2	4.962	21.905	0.000
RESIDUAL	12.006	53	0.227		

Equation 3.2

DEP VAR: MM5 N: 56 MULTIPLE R: .527 SQUARED MULTIPLE R: .278
ADJUSTED SQUARED MULTIPLE R: .250 STANDARD ERROR OF ESTIMATE: 14.815

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-111.726	33.345	0.000	1.0000000	-3.351	0.001
LWD1	21.464	5.975	0.420	.9988473	3.592	0.001
PH	10.689	3.747	0.333	.9988473	2.853	0.006

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	4470.726	2	2235.363	10.185	0.000
RESIDUAL	11632.222	53	219.476		

Equation 3.3

DEP VAR: LMWD N: 56 MULTIPLE R: .514 SQUARED MULTIPLE R: .265
ADJUSTED SQUARED MULTIPLE R: .251 STANDARD ERROR OF ESTIMATE: 0.369

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-0.533	0.572	0.000	1.0000000	-0.931	0.356
LWD1	0.656	0.149	0.514	1.0000000	4.408	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	2.648	1	2.648	19.434	0.000
RESIDUAL	7.358	54	0.136		

cont...

Appendix B cont.

Equation 3.4

DEP VAR: MM52 N: 56 MULTIPLE R: .484 SQUARED MULTIPLE R: .234
ADJUSTED SQUARED MULTIPLE R: .205 STANDARD ERROR OF ESTIMATE: 10.329

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-40.548	17.210	0.000	1.0000000	-2.356	0.022
LCLAY	9.068	3.544	0.326	.8898979	2.559	0.013
PH	5.759	2.768	0.265	.8898979	2.081	0.042

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	1727.711	2	863.855	8.097	0.001
RESIDUAL	5654.754	53	106.693		

APPENDIX C. Variables and data used.

Definitions of variables used in Appendix C.

No -	Sample number.
SER -	Three letter code of the soil series name. See Table 3 for the full name.
TEX -	Textural class.
E.Cs -	Erosion class (after Tajek et al., 1985).
SGP -	soil classification subgroup code. Corressponds to Classification column in Table 3.
pH -	pH test values.
S -	Percent sand content.
SVF -	Percent sand less the very fine sand fraction.
SI -	Percent silt content.
SVFS -	Percent silt plus very fine sand.
CL -	Percent clay content.
OM -	Percent organic matter (% organic C *1.724).
K -	The calculated K value of the USLE (by nomograph formula then converted to SI units)
K4 -	The calculated K value of the USLE restricted to a maximum organic matter level of 4 % (by nomograph formula then converted to SI units).
MWD -	Mean weight diameter in mm.
MM5 -	Percent of wet sieved sample passing 8mm sieve that is greater than 0.5 mm diameter.
MM2 -	Percent of wet sieved sample passing 8mm sieve that is greater than 2.0 mm diameter.
MM52 -	Percent of wet sieved sample passing 8mm sieve that is greater than 0.5 mm and less than 2 mm in diameter.
WD1 -	The mean count of waterdrops required for aggregate desintegration (see section 3.2.4).
WD2 -	The mean waterdrop count required for desintegration of the least variable 30 aggregates (see section 3.2.4).
SD1 -	The standard deviation of WD1.
SD2 -	The standard deviation of WD2.

Appendix C. Data for complete data set (sorted by sample number).

No	SER	TEX	E.Cs	SGP	pH	S	SVF	SI	SVFS	CL	OM	K	K4	MWD	MM5	MM2	MM52	WD1	WD2	SD1	SD2
1	HGV	SiL	5	8	6.1	12	9	65	68	23	4.05	0.038	0.039	0.74	37.6	13.0	24.6	35.4	34.6	5.4	3.1
2	KHS	CL	4	7	6.7	21	13	47	55	32	11.84	0.001	0.026	0.97	55.5	17.8	37.7	50.9	43.9	20.4	8.5
3	HGV	SiCL	5	8	6.3	16	8	51	59	33	4.34	0.027	0.028	0.59	47.9	6.9	41.1	34.4	31.9	9.5	3.7
4	HGV	CL	5	8	6.1	23	17	48	54	29	4.39	0.026	0.027	1.09	75.3	19.8	55.5	50.2	42.5	26.3	14.9
5	BTN	L	5	8	5.4	36	28	43	51	21	4.10	0.028	0.028	0.84	43.6	14.2	29.5	42.8	38.9	14.5	7.9
6	BTN	L	5	8	5.8	43	32	42	53	15	3.29	0.035	0.035	0.74	32.8	7.1	25.7	29.1	27.5	8.1	2.9
7	BTN	L	5	8	5.9	36	28	49	57	15	4.22	0.034	0.035	0.97	27.3	8.5	18.8	42.9	39.3	13.6	7.3
8	CAR	SiL	6	9	7.0	35	13	53	75	13	3.63	0.052	0.052	0.59	50.7	15.6	35.1	43.7	39.1	14.8	8.4
9	CAR	SiL	6	9	6.5	22	11	61	72	17	4.08	0.044	0.045	1.09	26.2	10.1	16.1	52.8	44.1	22.8	8.6
10	CAR	SiL	6	9	6.5	40	12	51	78	10	3.96	0.054	0.054	0.84	39.0	19.1	19.9	40.9	36.9	15.3	6.3
11	CAR	SiL	6	9	6.3	28	10	53	71	19	3.87	0.043	0.043	0.52	30.9	10.5	20.4	48.8	40.9	24.1	9.1
12	DMH	C	2	3	6.3	23	17	20	26	57	5.84	0.005	0.007	0.74	67.9	12.0	56.0	43.4	33.8	29.5	10.7
13	DMH	C	2	3	7.5	14	7	30	36	56	5.26	0.008	0.010	0.97	39.3	2.3	37.0	27.7	24.3	15.5	2.4
14	DMH	C	2	3	8.1	12	10	33	36	54	4.27	0.010	0.010	0.59	59.7	14.7	45.1	34.8	27.7	22.3	4.6
15	HKR	L	3	5	5.9	48	32	28	45	23	4.81	0.022	0.024	1.09	33.1	6.6	26.4	45.9	43.4	18.4	9.2
16	HKR	SL	3	5	5.2	54	39	29	44	17	5.22	0.022	0.026	0.84	16.1	6.2	9.9	32.5	31.5	5.5	4.3
17	HKR	SL	3	5	5.7	61	44	30	46	9	3.43	0.032	0.032	0.52	40.4	15.2	25.1	29.9	26.0	10.0	5.5
18	PHS	SL	2	1	6.2	73	54	11	29	17	6.54	0.011	0.016	4.60	178.7	118.2	69.9	72.5	64.0	30.6	22.0
19	FLU	CL	3	6	6.8	37	20	33	50	30	11.41	0.002	0.024	1.60	73.6	31.6	42.0	60.6	55.7	16.5	9.1
20	ATL	SCL	2	1	6.1	53	38	25	40	22	11.15	0.002	0.021	2.32	93.1	51.5	41.0	87.3	79.0	33.0	17.4
21	ATL	SCL	2	1	5.8	48	37	27	38	25	10.31	0.004	0.019	1.41	62.4	31.2	31.3	83.5	80.7	27.7	18.0
22	POK	L	3	2	6.2	45	34	40	51	15	13.19	-0.005	0.031	2.65	113.4	57.5	55.9	81.6	69.5	35.3	19.8
23	RMY	CL	3	6	6.0	39	24	34	48	27	9.25	0.008	0.024	0.93	47.4	17.0	30.4	47.8	47.5	11.9	7.2
24	RMY	CL	3	6	6.0	30	18	40	52	30	10.56	0.005	0.026	1.37	76.9	27.7	49.1	65.8	60.2	26.1	14.5
25	RMY	L	3	6	5.5	39	23	37	53	24	8.60	0.012	0.028	0.59	30.2	7.8	22.4	43.4	43.2	6.0	3.9
27	PHS	SCL	2	1	6.2	58	41	21	37	22	8.15	0.009	0.019	0.59	31.3	8.5	22.8	35.0	33.9	7.0	3.5
28	ATL	CL	2	1	6.7	36	30	35	41	29	9.93	0.005	0.020	0.65	33.7	10.5	23.3	39.0	37.6	10.2	5.9
29	PHS	SL	2	1	6.7	58	36	23	45	19	8.11	0.012	0.025	2.02	76.9	44.9	32.0	61.6	60.8	16.2	8.1
30	POK	L	3	2	6.9	37	24	44	58	18	9.29	0.012	0.034	0.90	56.3	14.8	41.5	40.1	39.3	7.4	3.9
31	POK	SiL	3	2	6.8	30	18	52	64	18	9.29	0.013	0.039	0.42	21.9	5.3	16.6	36.8	35.9	4.5	2.3
32	MMO	C	2	2	6.0	23	6	37	53	41	12.57	-0.002	0.021	1.43	67.6	27.8	39.8	97.7	80.9	54.1	39.8
33	MMO	C	2	2	6.4	14	9	32	37	54	9.29	0.004	0.011	0.63	48.5	8.7	39.9	53.1	44.3	34.9	15.2

Appendix C cont...

Appendix C cont.

No	SER	TEX	E.Cs	SGP	pH	S	SVF	SI	SVFS	CL	OM	K	K4	MWD	MM5	MM2	MM52	WD1	WD2	SD1	SD2
34	CMO	L	3	4	5.6	33	21	43	55	24	8.07	0.014	0.029	0.45	18.7	6.0	12.6	42.8	37.6	15.0	7.0
35	CMO	CL	3	4	5.8	41	29	32	43	28	5.95	0.016	0.021	0.37	15.2	3.9	11.2	39.1	31.8	19.6	6.3
36	FLU	SCL	3	6	6.8	45	33	28	40	28	7.01	0.012	0.019	0.40	18.5	4.8	13.7	31.1	30.2	5.9	3.3
37	RDW	SL	1	6	6.4	72	61	13	24	15	5.41	0.011	0.013	0.97	41.0	17.0	24.0	34.9	34.6	10.6	4.3
38	UCS	SCL	4	7	6.8	48	36	27	39	25	4.70	0.018	0.020	0.46	18.6	6.5	12.1	34.7	29.9	22.8	7.1
39	RDW	SL	1	6	6.4	72	52	14	35	13	4.21	0.020	0.020	0.70	39.4	9.4	30.0	28.9	26.9	7.6	3.9
40	FLU	SCL	3	6	6.3	47	32	27	42	26	9.71	0.006	0.022	0.50	21.4	7.0	14.4	37.6	37.1	6.1	3.4
41	UCS	SCL	4	7	6.5	52	42	23	33	25	10.02	0.004	0.016	0.81	38.5	13.3	25.2	38.9	37.6	7.9	4.7
42	UCS	CL	4	7	6.4	42	27	27	42	31	8.41	0.009	0.020	0.32	14.0	2.9	11.1	39.1	33.1	19.7	5.3
43	RDW	SCL	1	6	6.4	53	41	22	33	25	7.83	0.009	0.016	0.58	23.4	9.1	14.2	37.3	36.8	6.7	4.5
44	GOY	SiL	5	8	6.2	22	10	58	69	20	7.30	0.024	0.041	1.08	44.5	21.2	23.3	52.2	49.0	16.2	7.3
45	GOY	L	5	8	6.3	36	21	49	64	15	3.97	0.040	0.040	1.07	38.9	23.8	15.2	46.9	45.4	18.9	11.9
46	MMO	CL	2	2	6.1	28	14	45	59	27	6.37	0.021	0.031	0.39	15.8	5.1	10.7	45.2	39.8	18.1	5.9
47	CUL	LS	4	8	5.9	81	61	12	32	8	3.18	0.022	0.022	0.85	47.0	12.3	34.6	27.3	26.6	7.8	4.1
48	CUL	SL	4	8	6.5	75	51	15	40	10	3.06	0.028	0.028	1.08	46.6	19.3	27.3	31.9	28.7	17.5	5.9
49	CUL	SL	4	8	6.0	70	28	20	62	10	2.82	0.048	0.048	0.47	17.4	7.0	10.4	40.0	38.0	15.3	8.2
50	GOY	SiL	5	8	5.7	36	9	51	78	13	3.24	0.057	0.057	0.62	21.1	10.8	10.3	42.8	40.9	14.3	7.7
51	MYW	SiL	5	8	5.8	21	15	58	64	21	3.89	0.037	0.037	0.46	16.5	6.9	9.6	32.2	32.0	4.4	3.1
52	MLA	SiL	4	7	5.2	26	18	51	59	23	5.60	0.026	0.033	0.41	15.6	5.5	10.0	37.2	37.2	6.8	4.1
53	MYW	CL	5	8	6.1	22	13	45	54	33	4.18	0.025	0.026	1.48	61.7	32.2	29.5	106.6	93.2	53.0	36.1
54	MLA	CL	4	7	6.1	23	16	47	54	30	5.56	0.021	0.027	0.85	38.4	15.7	22.7	51.5	44.4	22.8	11.2
55	MYW	SiL	5	8	5.6	24	16	53	62	22	3.89	0.035	0.035	0.45	18.1	6.5	11.6	43.0	42.5	11.3	4.9
56	MLA	CL	4	7	5.9	20	15	44	49	36	6.83	0.014	0.022	1.48	64.2	29.9	34.3	92.7	74.1	56.9	31.3
57	KHS	SiCL	4	7	6.8	15	10	55	60	30	8.78	0.012	0.029	1.43	56.8	31.3	25.5	114.5	93.3	51.8	27.1
58	KHS	SiL	4	7	6.9	21	9	53	64	27	6.90	0.022	0.034	0.44	16.5	6.6	9.9	62.2	61.3	16.9	8.9
59	HGV	SiL	5	8	6.2	21	12	53	62	26	3.68	0.035	0.035	0.78	30.7	15.3	15.5	55.0	50.1	18.9	10.3
60	KHS	SiCL	4	7	6.4	17	12	43	49	39	5.51	0.016	0.020	0.73	29.0	12.4	16.5	100.0	96.5	58.5	45.5
61	COA	L	5	8	6.2	46	38	40	48	14	4.13	0.029	0.030	1.07	45.4	20.4	25.0	78.5	58.2	55.1	22.4
62	COA	L	5	8	6.2	37	27	45	55	18	3.85	0.033	0.033	0.97	35.5	18.2	17.3	55.9	54.6	19.8	11.2
63	COA	L	5	8	5.7	42	28	45	58	14	3.82	0.037	0.037	0.83	30.8	15.4	15.4	68.6	66.2	30.6	15.3
64	CMO	L	3	4	6.0	37	27	38	48	25	7.48	0.014	0.025	0.44	35.8	12.8	23.0	72.0	71.3	31.4	20.9